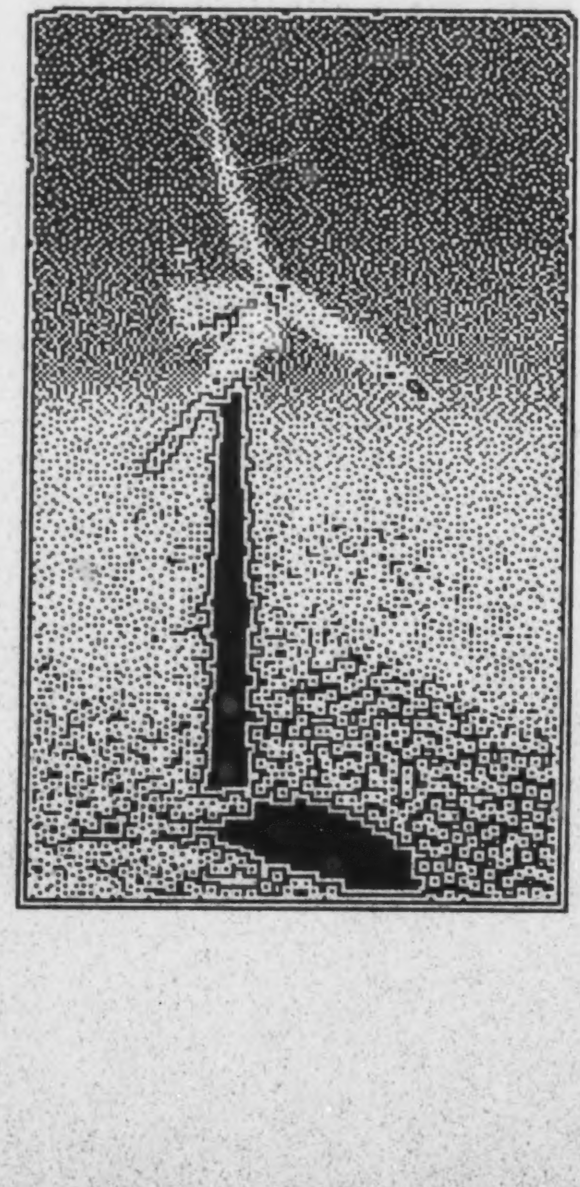
ÉNERGIE ÉOLIENNE '91

Conférence '91 de
l'Association Canadienne
de l'Énergie Éolienne

Montréal, Québec,
4 au 7 novembre 1991

Canadian
Wind Energy
Conference '91

Montreal, Quebec
November 4 - 7, 1991



WIND POWER '91

93-00311/

PROCEEDINGS OF THE SEVENTH
ANNUAL NATIONAL CONFERENCE OF THE
CANADIAN WIND ENERGY ASSOCIATION (CanWEA)

Le Grand Hotel
Montreal, Quebec
November 4 - 7, 1991

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MARCH 1992

ACKNOWLEDGEMENT

The Canadian Wind Energy Association (CanWEA) would like to thank all of those who devoted their efforts to make this seventh conference of our association a success:

Real Reid of Hydro-Quebec, who coordinated much of the planning;

Passmore Associates, the conference organizers, who exceeded our demands for an efficient and smoothly run conference; and

Our sponsors, CANMET/Energy, Mines and Resources Canada, the Quebec Ministry of Energy and Resources, and Hydro-Quebec.

Many thanks to our loyal members who attended, many of whom presented interesting and informative papers, to the exhibitors, and to our corporate sponsors.

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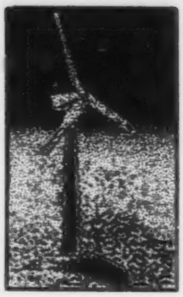

CANADIAN WIND ENERGY ASSOCIATION

Proceedings of the

SEVENTH ANNUAL WIND ENERGY CONFERENCE

November 4 - 7, 1991

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Canadian Wind Energy Conference '91

PRESIDENT'S MESSAGE

The 1991 Canadian Wind Energy Association annual conference in Montreal was very successful. It would seem that CanWEA has been able to improve its annual conferences for the past three years. This may be the result of the recent increase in environmental awareness which goes hand in hand with increasing interest in wind energy.

The theme of the seminar, "The Social Costs of Electricity Generation", and the quality of the speakers, including Hohmeyer, Caverhill, King, and Lundsager, drew attention to wind energy as a clean environmental method of generating energy. The seminar demonstrated that wind is one of the few forms of energy acceptable under a "sustainable growth" economy.

As in past years, Passmore Associates was the conference organizer and, as in past years, their performance in organizing and operating the conference greatly contributed to its success.

The location of the conference at Le Grand Hotel in downtown Montreal was a good choice. The service was excellent, the hotel staff were great, and the location allowed evening walks in old Montreal.

Thanks to the support of Energy, Mines and Resources Canada, CANMET, Quebec's Ministry of Energy and Resources, Hydro-Quebec, U.S. Windpower, Nor'wester, Island Technologies, and SNC-Lavalin, we were able to offer a good quality conference to our members and guests.

We were fortunate to be honoured with quality speakers: Mr. Dave Kilgour, M.P., spoke at the banquet; Ian Goodman, of The Goodman Group, spoke at the seminar luncheon; and Jean Giroux, assistant deputy minister of Quebec's Ministry of Energy and Resources spoke at the Wednesday luncheon.

The papers and discussions were of high quality with a high proportion of international speakers, a direct result of the low R&D spending in Canada. The mood was upbeat based on the increased R&D budgets and achievements both in Europe and in the U.S.A. Despite economic hard times, a strong group of exhibitors representing three manufacturers/distributors of wind turbines, one manufacturer/distributor of monitoring equipment, several government departments and agencies, and one utility were present.

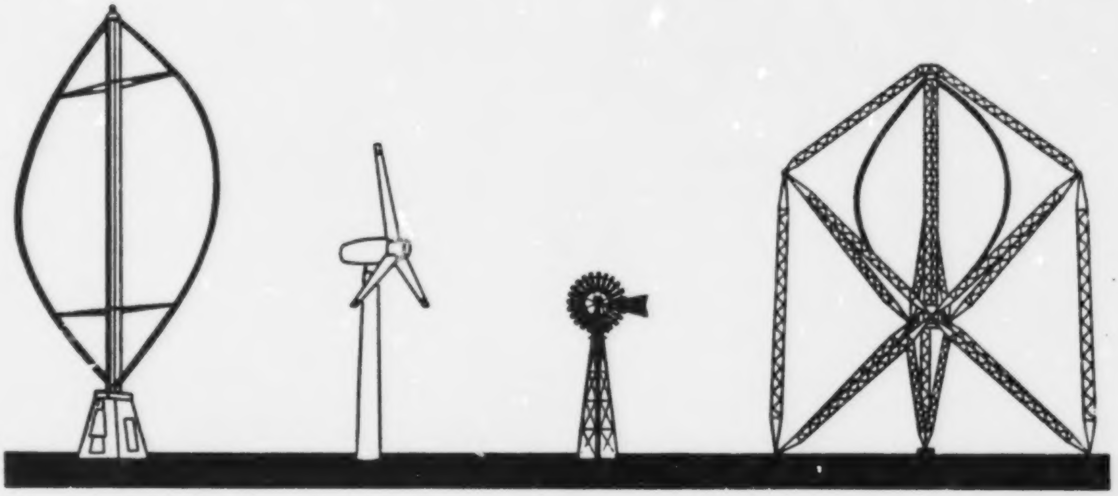
I would like to thank all the individuals who worked hard to make this conference a success, particularly the conference committees and CanWEA directors. This year conference attendees left with the feeling that continued technological progress and environmental challenges coupled with the drive of the few forward thinking Canadians that make up the wind energy industry will contribute to the deployment of wind energy throughout Canada over the next 10 to 20 years. I am looking forward to witnessing this progress at the coming annual conferences.

Real Reid, 1991 CanWEA President

The
R. J. TEMPLIN
AWARD

For outstanding contributions
to the development of
Canadian wind energy technology

Raj Rangi



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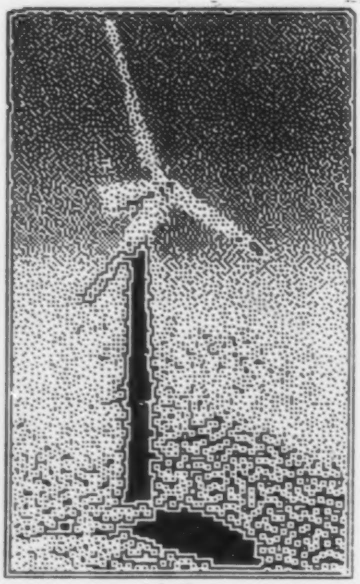
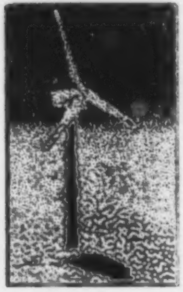
November, 1991



EMR
WIND ENERGY
SEMINAR

"The Social Costs

of Electricity Generation"



CALCULATION METHODOLOGY

Evaluation of Social Costs

The Social Costs of Electricity Generation

Effects of Social Costs on Wind Energy

Dr. Olav Hohmeyer

Fraunhofer-Institut für
Systemtechnik und
Innovationsforschung

Karlsruhe

FR Germany

O. Hohmeyer, FhG/ISI, 10/1991

13.09.89

Categories of social costs analyzed (quantified and monetarized):

1. Environmental effects:
   - flora
   - fauna
   - human health
   - materials
   - climate (only a very small part of the actual damages are included)

2. Macroeconomic effects:
   changes in:
   - employment
   - gross value added
   - imports
   - income and expenditure of government and social security system

3. Depletion of non renewable resources, intertemporal misallocation due to low present resource prices

4. Government subsidies:
   - monetary subsidies
   - non monetary subsidies
   - R & D subsidies

- All monetarizations are subject to varying degrees of uncertainty

13.09.89

Categories of social costs not analyzed in the study:

1. Psycho-social costs of serious illnesses or deaths.

2. Environmental effects of intermediate production.

3. Environmental effects of fuel cycles (specifically of the nuclear fuel cycle).

4. Environmental risks of routine operation of nuclear power plants.

5. The full costs of climatic changes.

6. Hidden subsidies for energy systems.

7. Damages due to energy systems presently unknown.

Assessment of environmental externalities (fossil)

1. **Gathering** of all **available studies** on enviromental damages of air pollution **including cost estimates**
2. **Comparison** of the differing figures and **estimation of** probable **range of damage costs** for each damage category
3. Analysis of absolute **emissions of major air pollutants** by sector **in kt/year** (base year 1982)
4. **Weighing kt emissions by MAK-factors** (human toxicity) **and aggregation** to total kt emissions per sector
5. Calculation of the **share of kt emissions due to electricity** generation (≈ 28 %)
6. **Allocation of** proportionate **share of** the **damage costs** to electricity generation

    Total costs ≈ 5 - 27 billion $ (1 DM ≈ 0.5 $)
    electricity ≈ 1.4 - 7.6 billion $

Problems:
- static base year
- no cumulative effects considered
- no synergetic effects considered
- import/export of pollution neglected
- future effects neglected
- MAK values only for health damages applicable
- no improvements since base year considered

Assessment of environmental externalities (nuclear)

1. Only major **nuclear reactor accidents**
2. **Starting point** for health impact assessment **Chernobyl** accident
3. **Assumptions** on some preliminary 'extrapolation' of such type of accident to West Germany

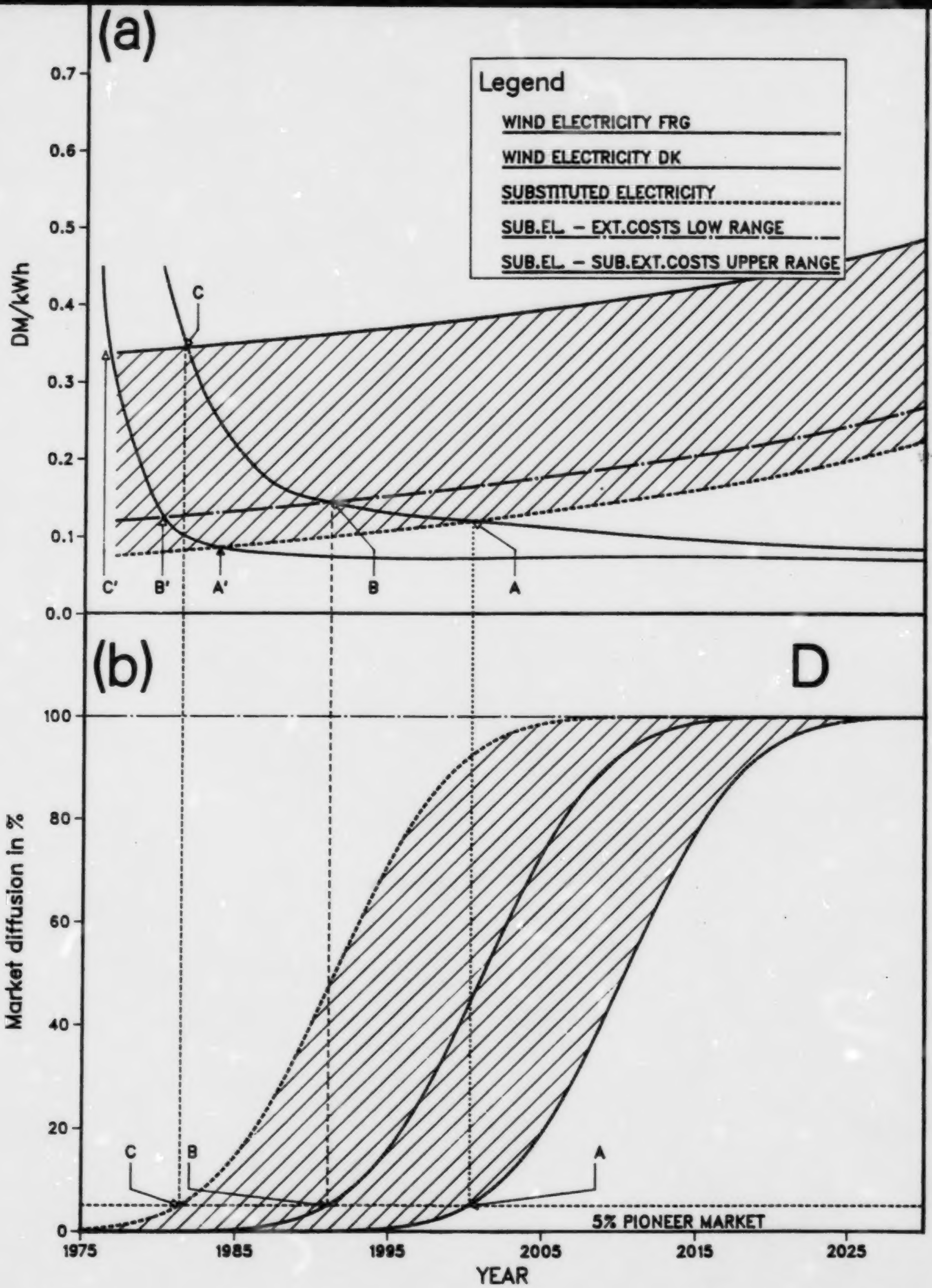
	Chernobyl	West Germany
- Released nuclear inventory	~ 4 %	same (?)
- Population density	25 pers/km^2	250 pers/km^2
- Biological dose (rem)	240 mio pers rem	2400 mio pers rem
- Cancer incidents per mio pers rem	~ 1 000 (200 - 3 700)	
- Resulting cancer incidents per accidents	240 000	2 400 000
- Production loss per cancer incident	~ 750 000 DM	
- Probability of core melt down with containment rupture per reactor year	~ $^1/_{3\,000}$	$^1/_{2\,000}$ - $^1/_{20\,000}$
- Total health costs per accident	180 billion DM	1 800 billion DM
Result:		
- Health costs per kWh$_{el}$	0.012 DM/kWh	0.012-0.12 DM/kWh

Problems:

- rest of fuel cycle not involved so far
- price tag for human lifes
- data on Chernobyl
- extrapolation of Chernobyl to West Germany
- probability of such accidents
- cancer incidents per mio pers. rem
- actual release of nuclear inventory

Tabelle 1: Vergleich der ursprünglich vom Autor berechneten sozialen Kosten und Nutzen der Elektrizitätserzeugung mit den Ergebnissen einer Neuberechnung vom dem Hintergrund der aktuellen Diskussion (Alle Angaben in Pf_{82}/kWh_{el})

	Hohmeyer 1989, S.13	Überprüfte Berechnungen 1990 incl. CO_2	
a) Soziale Bruttokosten der Elektrizitätserzeugung auf der Basis fossiler Brennstoffe (alle Zahlen sind geschätzte minimale externe Kosten)		Emissionen 82	Neuanlagen 90
1. Umweltschäden	1,10 - 5,85	2,6 - 10,67	2,05 - 7,93
2. Ausbeutungszuschlag (Basisjahr 1985)	2,29	0,67 - 4,71	
3. Öffentlich bereitgestellte Güter und Dienstleistungen	0,07	0,06	
4. Finanzielle Subventionen (incl. Steuererleichterungen)	0,32	0,30	
5. Öffentliche Zahlungen für Forschung und Entwicklung	0,04	0,02	
Summe	2,94 - 8,54	3,65 - 15,96	3,11 - 13,03
b) Soziale Bruttokosten der Elektrizitätserzeugung auf der Basis nuklearer Brennstoffe, ohne Berücksichtigung neuer Reaktorlinien (alle Zahlen sind geschätzte minimale externe Kosten)			
1. Umweltschäden (nur Gesundheitsschäden)	1,20 - 12,00	3,48 - 21,0	
2. Ausbeutungszuschlag (Basisjahr 1985)	5,91 - 9,88	4,88 - 47,42	
3. Öffentlich bereitgestellte Güter und Dienstleistungen	0,11	0,11	
4. Finanzielle Subventionen	0,14	0,14	
5. Öffentliche Zahlungen für Forschung und Entwicklung	2,35	1,46	
Summe	9,71 - 24,48	10,06 - 70,13	
c) Mittlere soziale Bruttokosten der in der Bundesrepublik erzeugten Elektrizität (Gewichte 1984)		Alte fossile Kraftwerke	Neue fossile Kraftwerke
1. Soziale Kosten der aus fossilen Brennstoffen gewonnenen Elektrizität (Gewichtsfaktor 0,705)	2,07 - 6,02	2,58 - 11,25	2,19 - 9,19
2. Soziale Kosten der aus nuklearen Brennstoffen gewonnenen Elektrizität (Gewichtungsfaktor 0,237)	2,30 - 5,80	2,38 - 16,62	
Summe (konv. Elektrizität wird unten verrechnet)	4,37 - 11,82	4,96 - 27,87	4,57 - 25,81
d) Nettonutzen der Windenergie			
1. Umweltschäden (Lärm)	(-)0,01	(-)0,01	
2. Öffentliche Zahlungen für Forschung und Entwicklung (einschließlich geschätzter zukünftiger Zahlungen)	-0,26 - (-)0,52	-0,16 - (-)0,33	
3. Makroökonomische Nettoeffekte	+0,53 - (+)0,94	+0,47 - (+)0,78	
4. Vermiedene soziale Kosten der konventionellen Elektrizitätserzeugung (s.o.)	+4,37 - (+)11,82	+4,96-(+)27,87	(+)4,57-(+)25,81
Summe der sozialen Nettonutzen auf eine Kommastelle gerundet	+4,6 - (+)12,2	5,26 - 28,32	4,87 - 26,25
Mittelwert	(+) 8,4	16,8	15,6
e) Nettonutzen der Solarenergie (Photovoltaik)			
1. Umweltschäden	(-)0,44	(-)0,44	
2. Öffentliche Zahlungen für Forschung und Entwicklung (einschließlich geschätzter zukünftiger Zahlungen)	-0,52 - (-)1,04	-0,33 - (-)0,65	
3. Makroökonomische Nettoeffekte	+2,40 - (+)6,65	+2,35 - (+)8,35	
4. Vermiedene soziale Kosten der konventionellen Elektrizitätserzeugung (s.o.)	+4,37 - (+)11,82	+4,96-(+)27,87	(+)4,57-(+)25,81
Summe der sozialen Nettonutzen auf eine Kommastelle gerundet	+5,8 - (+)17,0	+6,54-(+)35,13	(+)6,16-(+)33,07
Mittelwert	(+)11,4	20,8	19,6



Impact of external costs on the economics
of electricity generation from wind energy (1975 to 2030)
1982 prices – commodity charge only, foss.new (1990)

Answers to the three central questions:

- 1. The difference in the social costs between conventional electricity and renewables is quite substantial
  - Delta wind energy: 5 - 28 Pf/kWh (3 - 16 US c/kWh)
  - Delta photovoltaics: 6 - 35 Pf/kWh (4 - 20 US c/kWh)
- 2. This difference creates a substantial competitive disadvantage for wind energy today
- 3. Ignoring social costs delays the market introduction of wind energy systems by many years
  - In Germany: 9 -19 years

Political implementation:

- **Germany:**
  - 250 MW wind program (8 Pf/kWh, 4.6 US c/kWh)
  - buy back rate raised from 8 to 17 Pf/kWh (4.6-9.7 c)
- **CEC:**
  energy tax planned: 3 - 10 US$/barrel equivalent
- **USA:**
  about 25 federal staates demand an inclusion of environmental costs in LCP and DSM in different ways

THE VALUATION OF EXTERNAL COSTS: AN OVERVIEW OF ISSUES AND STATE ACTIONS

Prepared for the
Canadian Wind Energy Association Conference 1991

Emily J. Caverhill
Resource Insight, Inc.[1]

1. Introduction

The valuation of externalities helps determine the cost-effectiveness of environmentally superior resources that would not be cost-effective on a direct cost comparison to utility avoided costs. Externalities valuation should be consistent across resource options and across pollutants and should allow selection of societally least-cost resources among a variety of resource types. Explicitly monetizing externalities appears to be the best way to meet these criteria.

We have adapted the following comments from comments we prepared on behalf of the American Wind Energy Association for the Minnesota Public Utilities Commission and testimony on behalf of Wisconsin Gas Company before the Public Service Commission of Wisconsin.

2. Recommended Sources

The estimation of external costs encompasses a number of policy, regulatory, economic, science and engineering disciplines. To help readers select a method for including externalities in utility planning we recommend the documents referenced in this paper as well as:

a. Environmental Costs of Electricity (Ottinger, et. al. 1990) for damage costing.

b. Externalities orders from other states (including Massachusetts, California, South Carolina, Nevada and New York.)

c. Scientific reports regarding global warming, for instance: (1) National Academy of Sciences, Policy Implications of Greenhouse Warming - Report of the Mitigation Panel, National Academy Press, 1991; and (2) U.S. EPA Office of Policy, Planning and Evaluation, Policy Options for Stabilizing Global Climate, Draft Report to Congress, February 1989.

---

[1] 18 Tremont Street, Suite 1000, Boston, Massachusetts, 02108.

d. Emissions and other externalities from specific resource options: utility plant data, EPA AP-42, EPRI TAG.

e. Current and future pollution control measures required in Minnesota and their costs. This information can be obtained from state and federal environmental agencies.

3. Definition of Environmental Costs

Environmental costs should be defined so as to not exclude any potential external effects, including all environmental, social and economic effects. A good general definition is all costs and benefits of electric resources not included in the costs of the resources to the utility or its ratepayers.

For practical purposes the definition could probably include only environmental externalities (excluding social and economic externalities) without materially affecting resource decisions in the foreseeable future for most North American utilities. Other states which have evaluated externalities have identified few important social or economic costs that are true externalities, rather than transfer payments, and the social and economic externalities are sometimes partially mitigated. However, if important social or economic externalities arise, they should be included in utility resource planning.[2]

More specifically, a comprehensive list of external costs should at least include:

a. emissions of the U.S. federal criteria pollutants SO_2, NO_x, PM-10, CO and lead,[3]

b. emissions of other regulated air pollutants, including volatile organic compounds (VOCs), air toxics, CFCs, and radionuclides including tritium,

c. emissions of unregulated but potentially harmful air emissions: particularly the greenhouse gases, including greenhouse gas emissions associated with large hydro-electric projects,

---

[2] Dr. Olav Hohmeyer has done extensive work on social costs for Germany and concludes that resource depletion is an important non-environmental externality among others. RII developed an externality value for imported oil, which could be important for New England utilities that are oil-fired on the margin, but is less important for coal-dominated utilities.

[3] Ozone is also a criteria pollutant, but is the product of a reaction between the ozone-precursors NO_x and VOCs in the atmosphere. It is not a direct emission from combustion.

d. thermal and chemical impacts and flowrate of regulated and unregulated (but potentially harmful) cooling water effluents,

e. regulated and unregulated (but potentially harmful) solid and hazardous wastes,

f. externalities unique to new nuclear capacity, such as additional risk of a catastrophic accident,

g. externalities unique to hydro-electric resources: mercury accumulation in reservoirs and destruction of habitat, recreational opportunities, and wilderness,

h. all other external costs and benefits that can materially affect the outcome of the resource selection process.

Identifying the external costs of the resource, such as its air emissions, and then investigating its unique benefits, if any,[4] helps simplify resource comparison. Often, the external benefits of one resource, such as wind, simply avoid the external costs of the alternatives, generally the marginal electric system.

4. Measurement of Environmental Costs

Environmental effects should be counted and then valued in order to be included in utility planning. Selecting environmental effects to measure largely depends on the chosen externality valuation technique. The most common methods of valuing effects are "damage costing" and "regulatory cost of control", with some variations on these two.

"Damage costing" (or "direct costing") counts the effects caused by a resource, such as the number of health effects, reduction in visibility, materials and crops damages, and impacts on ecosystems. A dollar value is placed on each unit of each effect: dollars per lost activity day, materials cost, etc. The effects with their dollar values determine an externality cost in cents per kilowatt-hour or equivalent units. If a utility commission determines that the value of damages can be individually estimated, it could adopt the damage cost approach and measure the direct effects of the resources. Bonneville Power Administration in the Pacific Northwest follows this path.

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[4] An example of a unique benefit would be a new efficient cogenerating power plant replacing an old dirty oil-fired steam boiler. While the cogenerator will have some air emissions, it might be appropriate for it to receive credit for avoiding the emissions from the old boiler.

For a more detailed description of the damage cost approach, including the measurement and valuation methods used in damage costing, see Environmental Costs of Electricity. The application of these methods to develop externality values is rudimentary, but this book provides some insight into the fledgling nature of this field for immediate application in utility planning. The New York Public Service Commission and electric utilities have begun a $1.3 million damage costing project.[5]

The "cost of control approach" (or "implied valuation") counts the emissions and effluents caused by a resource (per unit of output or another suitable measure) and estimates a dollar value for reducing each effect. Each effect is then combined with its dollar values to determine an externality cost in cents per kilowatt-hour or equivalent units. If a utility commission decides that the costs of environmental regulations imply a societal value for reducing environmental effects, it should adopt the cost of control methodology for measuring externalities. The California Energy Commission and the California PUC follow this approach. Some utility regulators adopt this method for practical reasons, even after expressing a preference for damage costing. States which have adopted control cost based externality values but expressed a preference for damage cost estimates include Massachusetts, Nevada and New York. The rationale behind this approach is that collecting data on the emissions and effluents from a resource is usually reported to environmental regulators already and is far simpler than estimating the damages caused by those externalities.

For a brief discussion of the strengths and weaknesses of these two approaches, with some emphasis on the cost of control approach, see Chernick and Caverhill, "Monetizing Externalities in Utility Regulations: The Role of Control Costs" presented at the National Association of Regulatory Utility Commissioners' National Conference on Environmental Externalities in October, 1990.

The discussions by utility commissions that have externalities orders in place also provide useful information. For instance, the Massachusetts DPU grappled with the measurement issue by addressing many smaller discreet issues: how should environmental costs be included in utility planning, which measurement and quantification techniques are feasible, which technique should be used, how will environmental costs be updated to reflect the dynamic regulatory environment, and so on.

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[5] The project is cofunded by the NYSERDA, the New York utilities and EPRI. The contract length is four years.

Subsequent to the Massachusetts DPU Order in August of 1990, a few utilities and other parties have proposed what they call a "market-based" approach to valuing externalities. They reason that if a market for emissions were established where emissions allowances would have to be purchased then the marginal cost of controlling emissions would be established by the market price of the emissions allowances. Establishing an emissions cap and a market for the remaining emissions may be effective to meet some air quality targets. However, there are several hurdles to overcome prior to using this method to establish externalities values in the absence of a market.

First, the appropriate emissions level or cap should be established. Ideally, such a cap would be based on a threshold emissions level below which effects are diminimus. However, strong evidence suggests that environmental regulators have not yet found such a level for most pollutants in real situations.[6] Reducing emissions beyond the cap may still be valuable. If there is no or a very low threshold below which there are no effects, the cap would probably be limited by what the regional economy could afford in terms of health and environmental effects and costs of further emissions reductions. This latter situation thus requires estimates of the values of reducing externalities which is derived independently from the cap.

If an appropriate target cap can be set, the second step is establishing an emissions baseline in the absence of the cap. The baseline should include the effects of regulatory reductions, economic growth, and other factors affecting energy use, like weather. From this baseline and emissions cap, the reductions required to meet the cap can be established. Third, a reduction inventory, including potential reductions and costs, should be established to determine a marginal supply curve for emissions reductions. The costs in the supply curve should include all transaction costs for administering and verifying emissions trades. Finally, the target emissions reductions should be matched to the supply curve to determine the marginal costs of meeting and maintaining the cap.

Such markets have been established for some urban areas in California. An emissions market is being established for national SO_2 emissions under the U.S. Clean Air Act Amendments of 1990 (CAAA). Additional emissions offsets, another market mechanism, will be required for ozone precursors in non-attainment areas under Title I of the CAAA. Utility commissions may want to consider emissions caps to achieve some environmental goals; however, it is likely that externality values will have to be independently established to set realistic emissions targets.

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[6] Some assert that the NAAQS are threshold limits for the criteria pollutants, that is, there are no effects if the ambient air level of a pollutant is below the NAAQS. This is clearly false for acid gases, where large regions that meet the NAAQS have substantial acid rain damage. Numerous other examples in the EPA criteria documents and scientific journals and reports indicate effects below the NAAQS.

5. Quantifying Environmental Costs

A frequent question is whether to report externalities by technology, fuel type, or another method. The Massachusetts DPU discusses this issue on pages 54 to 56 of its Order in Docket No. 89-239 (Attachment 3). The MDPU rejected a technology-based approach based on its failure to encourage pollution control innovation between like sources. It chose the "impact-based" method. This method entails valuing individual emissions, effluents, and other externalities independent of their sources to determine consistent externality values (in $/unit of the externality) across the state. The externality value ($/kWh) for each resource is determined by measuring its unique emissions, effluents and other externalities. As mentioned above, regulators already collect the amounts of many externalities, such as emissions of the federal criteria air pollutants and cooling water flowrate. Other externalities, like CO_2 emissions, are relatively simple to calculate based on fuel type and plant heat rate. For resources not yet operating, externalities can be estimated based on environmental permit levels, fuel and plant type and other operating characteristics. The California Energy Commission and PUC, the New York PSC, and the Nevada PSC use an approach similar to Massachusetts. The BPA appears to have chosen a technology-based approach.

6. Consistency Among Externality Sources

Allowing the utilities to develop unique externality values for their service territories would probably be consistent with traditional utility regulation. However, there is no inherent reason why the value of externalities should vary among utility companies or sources, all else being equal. Administering statewide or region-wide externality values should also be simpler, since the commission would approve only one set of externality values. All interested parties would be focussed on a collective externalities proceeding (or set of proceedings) rather than addressing the issue in every utility integrated resource plan and rate case.

Some favor adopting externality values that reflect the air quality, current control requirements, and other factors unique to a specific area rather than adopting statewide or region-wide externality values. The argument that the marginal value of avoiding or reducing such pollutants is different in rural areas with sparse population and cleaner air than that in urban areas. This is a particularly attractive idea for pollutants that appear to act locally, like carbon monoxide and the ozone precursors VOCs. These pollutants' effects largely depend upon background air quality and other pollution sources in the immediate area. However, few pollutants are strictly local in their effects: carbon monoxide emissions react in the atmosphere to form CO_2; and ozone caused by VOCs can travel with prevailing winds. For other externalities whose effects are global (such as the greenhouse gases carbon dioxide and methane), regional (such as acid rain precursors sulfur dioxide and nitrogen oxides) or local but outside the state (like coal or nuclear mine tailings) there is no reason to maintain different values in different parts of the region or state.

Some also argue that externality values are too high if they preclude the use of one or more resources that would otherwise be cost-effective. A simplified version of a debate in the Northeast is that the externality values currently used by the Massachusetts DPU appear to make all coal technologies uneconomic at any plant capacity factor. Of course coal developers are concerned, and others argue that new coal projects are desireable for fuel diversity reasons. If coal, or any other single resource, is desirable for fuel diversity reasons, then a fuel diversity externality or non-price factor should be included in the resource procurement process of the utilities. Lowering the externality values may achieve the intended result of this one interest group -- to make coal the selected resource for base-load needs -- but will discriminate against other resources that may have similar diversity benefits for the utilities and superior environmental attributes, like wind power. Externalities values should be set largely independently of their effects on utility resource selection.[7]

7. Specific Rules

In my experience, utilities generally prefer clear guidance from commissions on an acceptable externalities methodology, and sometimes on specific externality values. On the other hand, utilities generally want to maintain flexibility in the final choice of resources. The utility commission should be specific as is comfortable in setting its externalities guidelines, including formulas for avoided externalities and specific externality values. Utilities should be required to use the calculations and externality values set by their commissions between periodic reviews of the externalities issue. In keeping with this, utilities should use the societal cost test to compare new resources.

8. Avoided Externality Costs

Avoided externality costs should be estimated in a manner consistent with avoided cost estimation. That is, the system effects of new resources should be determined. New resources with different capacity factors will affect the existing system's costs and externalities in different ways; these system effects should be included when resources are compared.

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[7] If a utility commission determined that the effects of including specific externality values were unacceptable for some reason, it could choose to phase in the externality values.

Commissions should allow utilities to pay more for clean resources such as DSM and wind. Otherwise, external costs are excluded from the resource selection process by definition. On the other hand, the utilities should pay only the costs or bid price of the winning new resources.

If the goal of resource selection is maximizing public welfare, then a cost test that includes all costs to the utility and its shareholders, its customers, and society as a whole should be used.[8] This type of test is generally called the societal test or total resource cost test. Including external costs in resource analyses using this type of test is relatively straightforward if the externalities are "monetized," or their dollar cost has been estimated. Other common utility tests, including the utility cost test and the rate impact test, exclude external costs by definition. The cost test used by the utilities to compare resources will influence whether externalities are material to the selection of resources.

9. Summary of State Externality Activities

Approximately 35 states are considering or implementing integrated resource planning (IRP). Thirty utility regulatory agencies are considering the inclusion of externalities in utility planning.[9] Five of these report consideration on a qualitative basis; nine support quantification and valuation of externalities. Of the nine utility regulatory agencies with language supporting "monetization" of externalities, five have developed explicit externality values for utility planning. All of the orders requiring explicit valuation of externalities have occurred since 1989.[10] The balance of the states considering externalities reported in recent surveys that the inclusion of externalities is "under consideration" or "in progress."[11]

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[8] "Society" as used here should at least include the state or province, and might include areas outside the state or province for estimating external costs. The Massachusetts DPU includes external costs from outside the state; the Vermont PSC includes only externalities that affect Vermont residents in some fashion.

[9] See tables 1-3 for summaries of state actions in IRP and externalities.

[10] Other utility regulators, including the Northwest Power Planning Council and Wisconsin, required consideration prior to explicit monetization through the use of percentage adders for certain resources.

Approaches to considering externalities tend to fall in the general categories: set-asides, pilot projects or targets for resources considered to be "clean," such as DSM and renewable resources; overall emissions caps, such as the cap on national SO_2 emissions; emissions offsets, such as those required for new major sources of ozone precursor emissions required under the ozone provisions of the CAAA; and resource comparison mechanisms, including methods which fall in the spectrum from qualitative rating and weighting schemes to full monetization of externalities. All of these regulatory approaches are translated into emissions reductions through emissions control measures. Five utility regulatory agencies use the regulatory cost of control approach (California, Massachusetts, Nevada, New York and the Bonneville Power Association), four use adders (New Jersey, Vermont, Wisconsin, NWPPC),[12] two use preliminary damage cost estimates (BPA and New Jersey), and one has selected explicit monetization but has not selected a method (South Carolina).[13] The externality values selected by the states which explicitly monetize externalities are summarized in Table 4 and are briefly discussed below.[14]

a. California

The California Energy Commission (CEC) adopted externality values for six air pollutants in 1990.[15] In general, the CEC relied on two sources of valuation estimates for air emissions: the CEC staff and JBS Energy (whose work was on behalf on the Independent Energy Producers). The CEC adopted values developed by JBS Energy for the out-of-state NO_x and SO_x values, and by the staff for the other in- and out-of-state values. The staff approximated the marginal cost of control in the South Coast Air Quality Management District (SCAQMD), which surrounds Los Angeles and is the most polluted area of California. For each pollutant, the staff estimated the average cost of a subset of the very stringent control measures required in this area.

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[11] Tables 1-3 compile the results of three surveys regarding state IRP and externalities activities which generally confirm these statistics.

[12] Wisconsin may drop its adder approach; the NWPPC is the planning arm with territory overlapping with BPA.

[13] The Maine Public Utility Commission determined that monetization was not feasible for Maine at this time, but encouraged continued Commission participation in regional and national forums on the issue, and additional research by Maine utilities on the effects of monetization. (Environmental and Economic Impacts: A review and analysis of its role in Maine energy policy, Report to the 115 Maine Legislature Joint Standing Committee on Utilities, May 1, 1991, p. i.)

[14] Table 5 estimates $/kWh for several generation technologies based on the externality values in several states and typical emissions factors.

[15] California Energy Commission, 1990 Electricity Report. October 1990.

The resulting value was lower than the marginal cost of control in SCAQMD, but perhaps typical of the state as a whole. The out-of-state values the CEC adopted for particulate matter (TSP) and VOCs were proposed by the staff and are simply 1/10th the value proposed for within the state. The lower value was apparently supported by the general federal ozone level attainment status of the out-of-state regions that supply power to California. The SO_2 out-of-state value was based on mid-range scrubber costs on large power plants, while the NO_x value was based on an estimate of selective catalytic reduction (SCR) costs for NO_x control on gas-fired cogenerators of unspecified size.[16] Staff developed the CO_2 value used within and out-of-state largely from the costs and energy savings from planting trees for shade estimated in Akbari (1988).[17] All of the utilities use the same externality values.

The California Public Utilities Commission (PUC) recently adopted the CEC in-state externality values,[18] with some changes. The PUC requires the utilities to use the CEC in-state externality values initially, for both in-state and out-of-state emissions. The PUC also ordered the utilities other than Southern California Edison (which serves primarily the SCAQMD) to develop marginal control cost estimates for their respective dominant air basins and to use those values for all emissions.[19] The PUC did not address the difficulty of the utilities using different externalities methodologies for planning (under the CEC) and acquisition (under the PUC).

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[16] These estimates are briefly discussed in Schilberg, G.M. et al., Valuing Reductions in Air Emissions and Incorporation into Electric Resource Planning. August 1989.

[17] Akbari, H., et al., "The Impact of Summer Heat Islands on Cooling Energy Consumption and CO_2 Emissions," 1988 ACEEE Summer Study on Energy Efficiency in Buildings. ACEEE; Berkeley, Calif.: 1988.

[18] California Public Utilities Commission, Phase 1B Opinion: Changes to Final Standard Offer Four for use in Conjunction with the 1990 Electricity Report, pages 29-33. June 5, 1991.

[19] The CPUC estimates that the values will be similar, and possibly higher, than those developed for the SCAQMD and adopted by the CEC.

b. Massachusetts

The Massachusetts Department of Public Utilities (MDPU) adopted externality values for eight air pollutants in August, 1990.[20] The MDPU adopted externality values developed by Resource Insight and the Tellus Institute based on the marginal costs of control measures generally required nationally and in Massachusetts.[21] For the unregulated greenhouse gas emissions, the DPU adopted an externality value based on reasonable costs of tree-planting.

The MDPU is currently reviewing the externality values it adopted in 1990.[22] The scope of this proceeding includes revising the current externality values if sufficiently justified through new information, including the passage of the CAAA, and the addition of new externality values, such as air toxics and cooling water. New externality values based on control cost and damage cost estimates have been proposed in the initial round of testimony. Hearings will probably be scheduled in the first quarter of 1992.

c. Nevada

In February, 1991 the Nevada Public Service Commission adopted externality values based on the cost-of-control approach. The unit values are equivalent to those of Massachusetts (inflated to 1990$), except for the VOCs value, which reflects costs of controls for reducing fugitive VOC emissions from gasoline in Nevada. Nevada is also attempting to value H_2S (a major emission of some geothermal plants) and requires the utilities to determine values for the site-specific externalities water impacts and land use.

d. New Jersey

In September, 1991 the New Jersey Board of Regulatory Commissioners (formerly the Board of Public Utilities) adopted adders to reflect the environmental benefits of conservation.[23] These values are apparently based on the estimates in Ottinger, et al.

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[20] Massachusetts D.P.U. Docket No. 89-239, August 31, 1990.

[21] The CO_2 externality value was based on marginal domestic tree-planting costs.

[22] The current proceeding is a routine revisitation of the externalities issue where the burden of proof is on the party wishing to change or add to the current set of externality values (Massachusetts D.P.U. Docket No. 91-131).

[23] State of New Jersey Board of Regulatory Commissioners, Conservation Incentive Rule, N.J.A.C 14:12. September 25, 1991.

(1990).[24] The average environmental externality value is 2.0 cents/kWh for electric utility DSM programs,[25] and $0.95/MMBtu for gas utility DSM programs. These externalities are expressed in 1991 dollars and are to be adjusted annually with the GNP deflator index. The utilities use these externalities in setting avoided costs.

e. New York

To develop externality values for use in utility planning the New York Public Service Commission (PSC) relied partially on work done by the New York State Energy Office (SEO) in its 1989 state energy plan. In this plan, the SEO estimated the costs of various pollution control measures available in that state. As discussed in Putta (1990),[26] the control costs used by the PSC to develop externality values reflected a mix of high and low cost measures, except for CO_2, which was arbitrarily set at a small fraction (20%) of the SEO's original estimate of low-cost tree-planting. Land and water use externalities appear to be arbitrarily chosen.

As mentioned earlier, the New York PSC has also ordered the utilities to fund an environmental costing study of the direct costs of full fuel cycle externalities of power generation in New York. This study, cofunded by NYSERDA, ESEERCO, and EPRI will take approximately four years and cost over one million dollars. It will focus on developing damage costs of full fuel cycle external effects.

The NYSEO has recently released a new draft state energy plan (1991 biennial update), that includes updated control costs for SO_2 and NO_x, the costs of various CO_2 reduction measures and the costs of achieving emissions reductions targets.[27] This report shows control cost requirements for SO_2, NO_x and CO_2 to meet New York emissions reduction targets are more than twice those previously reported.[28]

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[24] Ottinger R., et al., Environmental Costs of Electricity, Pace University Center for Environmental Legal Studies, Oceana Press, 1990.

[25] This is an average value. The Commission asserts that the externalities should be time-differentiated by rating period but does not indicate how this should be done.

[26] Putta, S. 1990. Consideration of Environmental Externalities in New York States Utilities' Bidding Programs for Acquiring Future Electric Capacity.

[27] A summary of their estimates is provided in the 1991 Draft State Energy Plan biennial update, Issue 9, Table 11.

f. South Carolina

The South Carolina Public Service Commission (PSC) recently ordered utilities to monetize environmental externalities of supply- and demand-side options "where sufficient data is available," and evaluate externalities qualitatively where not enough information exists on their costs.[29] The PSC has not yet established a specific methodology for utilities to use in monetization or evaluation. The PSC also ordered the utilities to include the internalized costs of complying with both current and anticipated environmental regulations as part of the integrated resource planning process.

g. Bonneville Power Administration

The Environmental Cost Work Group was formed in 1990 to determine externality values for resource options in the Northwest. Resources evaluated by the workgroup include conventional and renewable resources. Preliminary externality values were determined for several externalities: SO_2, NO_x, CO_2, TSP, and proxies for water and land use. However, the Work Group recently dropped the CO_2 value from its analysis, citing uncertainty in costs.[30] The Work Group has also limited its fish impacts analysis in light of two other parallel efforts on the same topic. Where possible, the Work Group relied on direct environmental cost estimates developed by ECO Northwest.[31] The Work Group continues discussing the issues.

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[28] There are some odd assumptions in this report. Costs in the State Energy Plan were apparently calculated from nominal ratemaking costs provided by the utilities and real-levelized using a social discount rate of 3% real.

[29] South Carolina Public Service Commission Staff Docket 87-223-E, Integrated Resource Planning Process. August 28, 1991.

[30] The BPA is a federal agency, and was apparently under pressure from the U.S. to omit any valuation of the greenhouse effect.

[31] The ECO Northwest studies (1985, 1986, 1988) have been previously reviewed in Chernick and Caverhill (1989) and Ottinger, et al. (1990). These reviews find that the externality values derived by ECO Northwest are substantially understated.

10. Conclusion

Several states materially include environmental externalities in utility planning and several more are investigating the methods and issues surrounding externalities valuation. Wind power will benefit from externalities valuation; its advocates should become knowledgeable about the issues, and consider supporting like-minded DSM advocates, renewables, and even gas utilities in their attempts to have externalities explicitly included in utility planning.

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Company Background

Resource Insight, Inc. (RII) is a consulting firm specializing in utility regulatory issues and we are very active in the evaluation and inclusion of externalities in integrated resource planning. Our clients include utility regulatory commissions, public advocates, renewable energy developers and advocates, environmental advocates, gas and electric utility companies, and other private resource developers. We have provided comments and testimony on the topic of externalities in 12 states and one Canadian province.[32] We were principle co-authors of Environmental Costs of Electricity (Ottinger, et. al. 1990), and have spoken on the topic of including externalities in utility planning at several national and three international energy conferences. Ms. Caverhill is an advisor to NYSERDA and Correspondent to a recently initiated four-year damage costing project in New York.

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[32] California, Delaware, Illinois, Indiana, New York, Maine, Massachusetts, Minnesota, Pennsylvania, South Carolina, Vermont, Wisconsin, and Ontario.

Table 1
Integrated Resource Planning – Electric Utilities

State	Anticipated Capacity 10 Years [1]	Traditional IRP Rating [2]	"New Wave" IRP Rating [2]	Natural Gas IRP [2]	Gas LCP Status [3]
Alabama	P				Under Consideration
Alaska	P				
Arizona	P	2b	2		
Arkansas		1b			
California	P	4	4		Under Development
Colorado	P	1b	2		
Connecticut		2b	4		Under Development
Delaware	B,P	1	1		
Washington, DC	B,P	3b	1	Yes	*
Florida	B,P	3b	2		
Georgia	B,P	1b	1		
Hawaii	B,P	1b		Yes	Under Development
Idaho	B,P		1		
Illinois	B,P	4	2	Yes	In Implementation
Indiana	B,P	1b	2		
Iowa	P	3b	2	Yes	In Implementation
Kansas	B,P		1	UC	
Kentucky		2b			
Louisiana					
Maine	B,P	4	4		
Maryland	B,P	3b	3	Yes	
Massachusetts	B,P	4	4	Yes	Under Development
Michigan	B		2	UC	Under Consideration
Minnesota	B,P	2b	4		
Mississippi					
Missouri	P		1	UC	
Montana	*	1b			Under Consideration
Nebraska	*	*	*	*	
Nevada	B,P	4	3	Yes	In Practice
New Hampshire	B,P	4	3	UC	Under Consideration
New Jersey	B,P	3b	3	UC	In Implementation
New Mexico					
New York	B,P	4	4	Yes	Under Development
North Carolina	P	3b	2		
North Dakota	P	1b	1		
Ohio	P,B	2b	1		Under Consideration
Oklahoma					
Oregon	B,P	4	3	IP	In Implementation
Pennsylvania	P	2b	1		
Rhode Island	B,P		4	IP	Under Development
South Carolina	P	1b	1		
South Dakota	B,P				
Tennessee	*				
Texas		2b	1		
Utah			1	Yes	
Vermont	B,P	4	4	Yes	In Implemantation
Virginia	B,P	2b	2	Yes	
Washington	B	4	4	Yes	In Implementation
West Virginia	B,P				
Wisconsin	P	4	4	IP	In Implementation
Wyoming		1b		TBD	

Key:
* = No data given
No entry means: for column 1, "Neither," for 2 and 3, a rating of 0, for column 4, "No."
[1]: Anticipated capacity needed within ten years: B = Baseload, P = Peaking
[2]: IRP Ratings range from 0 to 4; a rating of 1b lies between 1 and 2.
UC = Under Consideration; IP = In Progress; TBD = To Be Determined

Sources:
[1]: NARUC, A Survey of State PUC Activities..., May 1990.
[2]: Mitchell, 1991 IRP Survey Update, September 1991.
[3]: Goldman & Hopkins, Survey and Analysis of Gas Utility IRP Efforts, in NARUC, Proceed., April 1991.

Mitchell ratings:
Traditional
0 = Little or no progress.
1 = Concrete proposals are before a body, but lack a key IRP element
1b = The IRP process is just beginning. It is too early to tell.
2 = Concrete proposals are before a body, are "full-featured" and are moving toward adoption.
2b = IRP framework has been established, but lacks many components needed to be full-featured.
3 = A full-featured IRP regulatory framework has been adopted.
3b = A full-featured IRP framework has been implemented, but lacks some components.
4 = A full-featured IRP framework has been adopted and implemented.

"New Wave"
0 = Little or no progress in DSM implementation. No consideration of bidding, incentives, externalities, or gas utilities IRP.
1 = Minor or no progress in DSM implementation. Some consideration of bidding, incentives, externalities, and/or gas utilities IRP.
2 = Some progress in DSM implementation. Active consideration of bidding, incentives, externalities, and/or gas utilities IRP.
3 = Possibly significant DSM implementation underway. Active consideration of bidding, incentives, externalities, and/or gas utilities IRP, with some implementation.
4 = Significant DSM implementation underway or has occurred. Implementation acheived in most of the following: bidding, incentives, externalities, and gas IRP.

Table 2
IRP and Externalities – Legislative requirements [1]

State	IRP Reg/ Statute	Bidding Reg.	Incentives Reg.	Ext. Reg.
Alabama				
Alaska	UC			UC
Arizona	R	IP	IP	IP
Arkansas	UC			
California	R	Yes	Yes	Yes
Colorado	IP; CL	Yes	Yes	TBD
Connecticut	R, S & CL	Yes	Yes	UC
Delaware		Yes		TBD
Washington, DC	R		IP	
Florida	CL	Yes	UC	Yes
Georgia	S		TBD	
Hawaii	R			
Idaho	CL	IP	UC	
Illinois	S	IP		IP
Indiana	S & CL	IP	IP	IP
Iowa	S & R		IP	Yes
Kansas		UC	Yes	UC
Kentucky	R			
Louisiana				
Maine	Yes	Yes	Yes	IP
Maryland	S	Yes	IP	IP
Massachusetts	Yes	Yes	Yes	Yes
Michigan		IP	IP	Yes
Minnesota	Yes	Yes	Yes	Yes
Mississippi				
Missouri		UC	UC	UC
Montana		TBD	TBD	TBD
Nebraska	*	*	*	*
Nevada	S & R	Yes & No	IP	Yes
New Hampshire	S & R		Yes	
New Jersey		Yes	IP	IP
New Mexico				
New York		Yes	Yes	Yes
North Carolina	R		IP	
North Dakota			IP	
Ohio	S & R	IP	Yes	
Oklahoma				
Oregon	Yes	IP	IP	IP
Pennsylvania	S & R		IP	
Rhode Island	S		Yes	Yes
South Carolina	IP; CL		IP	IP
South Dakota				
Tennessee				
Texas	S		Yes	IP
Utah		Yes		
Vermont	R	IP	Yes	Yes
Virginia	R	Yes	IP	IP
Washington	Yes	Yes	Yes	Yes
West Virginia				
Wisconsin	S		Yes	Yes
Wyoming	IP	TBD	TBD	TBD

Key:
* = No data given
No entry means "No."
S = Statute, CL = Case Law, R = Regulation
IP = In Progress, UC = Under Consideration,
TBD = To Be Determined

Source:
[1]: Mitchell, 1991 IRP Survey Update, September 1991.

Table 3
Externalities – PUC Actions

State	Status of PUC Activities [1]	Status of State Actions [2]
Alabama		
Alaska		O
Arizona	O	O
Arkansas		
California	O	O
Colorado	O	O
Connecticut	O	P
Delaware	A	
Washington, DC	D	U
Florida		
Georgia		
Hawaii	A	U
Idaho	O	O
Illinois	A	
Indiana		
Iowa	D	P
Kansas	O	O
Kentucky		
Louisiana		
Maine	D	U
Maryland	D	U
Massachusetts	O	O
Michigan	D	O
Minnesota	O	O
Mississippi		
Missouri	A	
Montana	*	U
Nebraska	--	
Nevada	O	O
New Hampshire	A	
New Jersey	O	O
New Mexico		
New York	O	O
North Carolina		U
North Dakota		
Ohio	O	O
Oklahoma		
Oregon	O	O
Pennsylvania	O	O
Rhode Island	D	U
South Carolina	A	
South Dakota		
Tennessee	--	
Texas	O	O
Utah	A	U
Vermont	O	O
Virginia	D	O
Washington	A	
West Virginia		
Wisconsin	O	O
Wyoming	A	

Key:
* = No data given
No entry means "None" or "No Action"
-- = State PUC does not regulate generating facilites
[1]: O = Operational, D = Developing Approaches, A = Awareness
[2]: O = Incorporation of externalities ordered,
P = Incorporation Pending, U = Under Consideration

Sources:
[1]: NARUC, A Survey of State PUC Activities..., May 1990.
[2]: Pace University, Environmental Costs of Electricity, 1990.

Table 4: Externality Values

Externality	Mass DPU values ($/lb)	CEC in-state values ($/lb)	CEC out-of-state values ($/lb)	Calif. PUC values ($/lb)	New York PSC values ($/lb)	New York SEO values ($/lb)	Nevada PSC values ($/lb)	BPA East values ($/lb)	BPA West values ($/lb)
SO2	0.78	6.48	0.56	6.48	0.43	1.1	0.78	0.20	1.80
NOx	3.38	6.53	1.52	6.53	0.93	2.1–4.4	3.40	0.03	0.44
CO	0.45	NE	NE	NE	NE	NE	0.46	NE	NE
PM10 (TSP for BPA values)	2.08	4.39	0.45	4.39	0.17	NE	2.09	0.08	0.77
VOC's	2.76	1.83	0.17	1.83	NE	NE	0.59	NE	NE
CO2	0.011	0.004	0.004	0.004	0.001	.03–.058	0.011	NE	NE

Sources:

California Public Utility Commission Decision 91-06-022. June 1991.

Massachusetts DPU Decision in Docket 89-239. August 31, 1990.

Nevada PSC Docket No. 89-752. January 22, 1991.

Ottinger, R. et al., "Environmental Costs of Electricity." Oceana; Dobbs Ferry, NY: 1990.

New York State Draft 1991 Energy Plan.

Bonneville Power Administration, "Environmental Costs and Benefits: Documentation and Supplementary Information." February 22, 1991.

Notes:

All values expressed in 1990$.

TABLE 5: SUMMARY OF STATE/ORGANIZATION EXTERNALITY VALUES FOR GENERIC POWER PLANTS

1990$/kWh delivered

State/Agency	Existing Eastern Pulverized Coal (1.2% S)	Existing Western Pulverized Coal (.4% S)	New Eastern Pulverized Coal (4% S)	New Western Pulverized Coal (.6% S)	Eastern Coal Fluidized Bed (4% S)	Western Coal Fluidized Bed (.6% S)	Gas Turbine	Advanced Gas Turbine	Gas Combined Cycle	Gas Cogeneration
Mass. DPU	$0.20	$0.06	$0.05	$0.05	$0.04	$0.04	$0.03	$0.02	$0.02	$0.02
CEC in-state	$0.73	$0.12	$0.10	$0.06	$0.07	$0.03	$0.02	$0.01	$0.01	$0.02
CEC out-of-state	$0.10	$0.03	$0.02	$0.02	$0.02	$0.01	$0.01	$0.01	$0.01	$0.01
Calif. PUC	$0.73	$0.12	$0.10	$0.06	$0.07	$0.03	$0.02	$0.01	$0.01	$0.02
NYPSC	$0.07	$0.01	$0.01	$0.01	$0.01	$0.01	$0.004	$0.002	$0.002	$0.003
Nev. PSC	$0.20	$0.06	$0.05	$0.05	$0.04	$0.03	$0.02	$0.02	$0.02	$0.02
NYSEO	$0.23–$0.35	$0.09–$0.18	$0.09–$0.18	$0.09–$0.17	$0.09–$0.15	$0.09–$0.15	$0.06–$0.15	$0.04–$0.08	$0.04–$0.06	$0.05–$0.09
BPA East	$0.02	$0.002	$0.002	$0.001	$0.001	$0.0003	$0.0001	$0.00004	$0.00004	$0.0001
BPA West	$0.15	$0.02	$0.02	$0.01	$0.01	$0.003	$0.003	$0.001	$0.001	$0.001

Notes:

Data from Tables 5.3–5.12.

Cogenerator externalities do not reflect any credit for reduced steam boiler operation. This factor should be taken into account and will appropriately reduce the net externalities of the cogenerator over its separated steam and electric counterparts.

EXTERNALITY COSTING FOR MAJOR HYDROELECTRIC PROJECTS: IS IT DESIRABLE? IS IT POSSIBLE?

Prépared for :

CANADIAN WIND ENERGY CONFERENCE '91

Prépared by :

Luc Bernier
Economist
Hydro-Québec

November 4, 1991

The subject of my remarks was chosen because so little research is being done at this time on externality costing for major hydroelectric projects.

This is a topic strewn with obstacles that must not be underestimated. However, we must recognize that energy generation projects imply trade-offs between material and environmental values. These trade-offs frequently provoke passionate discussions, full of emotion reminiscent of the religious wars in the past. As a result, decision-making requires the use of sophisticated methods, in order to eliminate most of the more arbitrary factors.

There are a number of methods that can be applied to such a context. However, the thoughts I would like to share with you mainly involve the assignment of monetary values to environmental and social impacts or, more simply, externality costing. Let me reassure the more skeptical among you that I do not exclude the parallel use of other methods that might resolve environmental conflicts, such as the collaborative process. However, to completely ignore methods intended to cost externalities would deprive us of information I believe to be essential.

You will also note that the valuation problems I mention essentially involve environmental externalities. I think that in Canada there is a somewhat broader consensus on the treatment of other externalities, such as support for employment in disadvantaged regions.

The Economic Approach to Externality Costing: Its Strengths and Weaknesses

The economic approach to costing externalities is different from other approaches in a number of ways:

- it seeks to quantify a maximum of the dimensions involved in a choice and to express them according to a monetary standard;
- it minimizes the arbitrary and value-based input to the decision-making process;
- it tries, to the extent possible, to evaluate the relative importance of the various dimensions of a problem, based on data from the real behavior of individuals.

The systematic application of externality costing techniques, however, requires a great deal of information and has its own scientific limits. Certain issues related to a decision are more difficult to value than others, usually because of ethical and methodological problems. To overcome these problems, it is sometimes necessary to invest a great deal of effort.

Some critics charge the economic approach with being "obsessed" by costing fundamental values, such as human health or specific cultural values. We all know that there are ethical problems enough to justify many long nights of discussion.

Nevertheless, we must also recognize that there always remains an implicit monetary value given to these dimensions, whatever approach is adopted. Externality costing simply makes it possible to make decisions on the basis of values reflecting real social preferences, as revealed in the decisions made by various economic agents when placed in various situations.

Which Estimates Cause the Most Methodological Problems?

Many of you may suspect that it is easier to assign a monetary value to land used for commercial purposes than to land used for supporting wildlife. Likewise, it is easier to conduct the same exercise for a wildlife habitat closely associated with hunting or fishing activities rather than for the habitat of species not so used. We might thus note the very close relationship between the reliability of a value attributed to an externality and the association of the resources involved and commercial activities.

The problem we must face is related to the fact that the environmental externalities associated with the generation of electricity very often involve resources that have little or no relation with the market. This is true, for example, of problems related to the disposal of nuclear waste, greenhouse gas emissions or major disturbances of an area caused by hydroelectric projects. For these reasons, values obtained will always remain approximations, whether the project under consideration is thermal, hydroelectric, wind or nuclear.

We know, therefore, that there are problems in obtaining reliable estimates of the value of externalities, whatever type of energy project is considered. If recent efforts on quantification have focused mainly on atmospheric emissions, it is for the simple reason that most of the electricity generating projects in North America burn fossil fuels.

A Few Remarks about the Valuations of Greenhouse Gases

Although my speech is supposed to deal mainly with hydroelectric projects, it is worthwhile to take a look at the work done on atmospheric emissions, especially on greenhouse gases. It can provide some useful lessons for quantifying the externalities of hydroelectric projects. I have noted two particularities about the valuation of externalities of thermal generating stations, and these also occur in relation to hydroelectric generating plants although in a slightly different form.

The first of these is related to the fact that scientists still know very little about the exact consequences of the release of greenhouse gases into the atmosphere. Humanity must therefore cope with a risk that has the potential for disrupting the ecology of the whole planet without being able to really appreciate the nature of the disruptions involved. We are still quite far from establishing a valid quantified projection of the anticipated rise in temperature and farther still from quantifying the possible effects of this potential warming. Yet it is this quantification that would constitute the main input for an externality costing exercise respecting the rules of cost-benefit analysis. In other words, we have very little information on the real impacts and their consequences.

This first finding may also be relevant to the impacts of major hydroelectric projects. Many hypotheses have been proposed on the impacts of such projects but there is very little consensus. For exemple, marine biologists do not necessarily agree on the impacts that occur in the estuaries of some rivers subject to dyking.

A second feature of the impacts of atmospheric emissions reflects the fact that the impacts are well in excess of simple deterioration of material goods or recreational activities that have some relationship to the market. We are attempting to judge the desertification of large portions of the continent, famines, major upheavals in climatic zones and ecosystems, etc. For this reason, it is impossible to limit the externality costing to impacts that affect the resources associated with a particular market. If we want to take into account the major issues of energy projects, we must extend the valuations to such areas as human health and the preservation of ecosystems in their current state.

Again, there is a great deal of similarity with the externalities of hydroelectric projects.

Faced with these obstacles, when attempting to value greenhouse gases, researchers have tried to go at the problem from an approach based on control costs. The validity of this approach depends, however, on the possibility of setting national targets for the control of the environmental problem concerned. As far as CO_2 is concerned, that is the approach that now dominates and is the only source of information.

Would it be possible to apply such an approach to hydroelectric projects? As I see it, no! For the simple reason that we don't have exact and homogeneous measurement units for the impacts generated by the different types of projects. In the case of atmospheric emissions, it is the number of tons emitted that play this role. In the case of hydroelectric projects, wildlife habitats are indeed altered but they are too heterogeneous and all play different ecological roles.

How to Approach Hydroelectric Projects

Prior studies of the environmental externalities of hydroelectric projects have all involved the values associated with the use of resources. That is why, for example, there have been studies of the value of a group of displaced activities, such as farming, recreation, forestry, etc. Values strictly related to conservation have rarely been included, at least not explicitly. This orientation is probably a result of the fact that the projects take place mainly in regions already exploited by man. As a result, it has not been necessary for externality quantification to address this type of concern.

In the case of the large hydroelectric projects planned in northern Canada over the next decade, the context of intervention will be different. Most of the facilities will be installed very far from regions subject to intensive use. For this reason, For this reason, it would be a mistake to think that an approach excluding non-use values could measure the main externalities. In order to measure this type of value, researchers are now using the contingent valuation method. This method consists of asking respondents about their willingness to pay for avoiding an impact or an environmental risk. All other methods, which" obtain their information essentially from real behavior, are not adapted to these circumstances.

The main problem we have to face is the validity of results obtained by the application of the contingent valuation method. It is criticized for generating values that reflect the willingness of respondents to buy a degree of moral satisfaction. It is suspected that some valuations obtained are more influenced by the formulation of the questions than the real importance respondents ascribe to the externality about which they are questioned. This criticism is particularly relevant when the contingent valuation method is applied for purposes of valuing resources with which the respondents have never had any contact.

In view of these methodological problems, it seems to me it is necessary to find another solution. It may be found in one of the criticisms addressed to the contingent valuation method: to avoid overly hypothetical situations and problems related to the purchase of moral satisfaction, it is necessary to avoid questions that focus are too directly on willingness to pay.

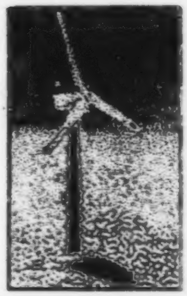
Instead, on an experimental basis, there could be a review of the trade-offs between several possible environmental impacts, defined in a precise manner. Such an exercise should preferably take place in a quantitative framework in which each respondent could, for example, be asked to allocate an environmental budget among various priorities. If such a quantitative framework were respected, it would then be possible to derive substitution rates between the various choices presented.

The goal of such an exercise would be to situate the impacts of hydroelectric projects among a series of environment impacts whose value is known or measurable. In this way, it would be possible to derive value intervals for the environmental externalities of hydroelectric projects.

To my knowledge, this path has so far remained little used. There are many possible questions. One of them would be the aggregation of environmental impacts related to the hydroelectric option. Should respondents be asked to give their opinion on the relative importance to each of the projected impacts or on all the impacts considered as a whole? Would the selected approach influence the results obtained? To find out, this experiment would first have to be tried.

It would also be foolish to claim that such a method would be bias-free. Likely any approach using a survey, we would have to expect that the results to be sensitive to the formulation of the questions and the information provided to the respondents. That is a source of bias that is difficult to eliminate. We cannot forget that the importance of certain impacts remains a matter of opinion, and that opinion will always be sensitive to the information received.

Finally, it is difficult to consider all the externalities of a mega-project using economic methods. Socio-cultural impacts represent a type of externality we could not expect to evaluate. As a result, the cost of an energy option, including the cost of externalities, could not be seen as the only decision-making criterion. On the other hand, this cost could play the same role that a financial statement plays for a manager. Such data is not the only criterion but how could we imagine doing without it?



ENVIRONMENTAL ASPECTS

ENVIRONMENTAL EXTERNALITIES AND RENEWABLES: A POLICY PERSPECTIVE

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* The views and opinions expressed in this paper are solely those of the author and do not necessarily state or reflect the views, opinions, or policies of the New York State Energy Office.

ENVIRONMENTAL EXTERNALITIES AND RENEWABLES: A POLICY PERSPECTIVE

INTRODUCTION

Environmental externalities impose tangible costs on society. Consideration of these costs in decision-making in a clear and concise manner will improve use of energy resources and improve the economic competitiveness of renewable resource technologies to other electricity generation alternatives.

The existence of environmental externality costs has been recognized in New York State. The New York State Public Service Commission (NYPSC) was the first state in the nation to require consideration of environmental externality costs in electric utility resource planning.[1] They require New York's investor owned utilities to quantitatively incorporate the consideration of environmental externality costs in their bidding programs for new capacity. For this purpose, the NYPSC adopted a 1.405 ¢/Kwh environmental externality cost for a coal plant which meets federal New Source Performance Standards (NSPS).[2][3] The components comprising the 1.405 ¢/Kwh cost are summarized in Table 1. It should be noted that, the cost estimates for SO_2 and NO_x were developed by the New York State

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[1] NYPSC, Opinion 88-20, Case 29409, "Proceeding on the Motion of the Commission to Examine Plans for Meeting Future Electricity Needs in New York State." June 3, 1988.

[2] NYPSC, Opinion 89-7, Case 88-E-241, "Proceeding on the Motion of the Commission as to the Guidelines for Bidding to Meet Future Electric Capacity needs of Orange and Rockland Utilities", April 13, 1989.

[3] NYPSC, Case 88-E-241, Order Issuing Final Environmental Impact Statement and Adopting Staff's Response to Agency Comments, Orange and Rockland Utilities.

Energy Office (SEO),[4] the estimates for CO_2, particulates, land and water are judgmental values by NYPSC staff.

Table 1

Externality	Economic Cost (¢/Kwh)
Sulfur oxides	0.25
Nitrogen oxides	0.55
Carbon dioxide	0.10
Particulates	0.005
Total Air Emissions	~~[illegible]~~ 0.905
Water discharges	0.10
Land use impacts	~~[illegible]~~ 0.40
Total Cost	1.405 ¢/Kwh

In New York's investor owned utility (IOU) bidding programs, an environmental point score is considered along with the price score in the ranking and selection process. Across New York's seven IOUs, the points awarded to environmental considerations, the "environmental adder", are on the order of 21 to 23 percent of the points awarded for price considerations.[5] This percentage defines the equivalent price advantage awarded to environmentally preferable projects.

Although the consideration of environmental externality costs is shaping New York's energy programs and policies, more can be done for including the full impacts of environmental externalities in energy resource decisions. A natural extension would be to consider environmental externality costs in the State's implementation of federal regulations under the Public Utilities Regulatory Policies Act (PURPA). A more direct approach, but one which is likely to be politically more difficult to implement, would be the use of environmental taxes.

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[4] The externality costs for SO_2 and NO_x were developed by the New York State Energy Office in a preliminary draft of the "Environmental Externality Issue Report" of the '89 State Energy Plan (February 24, 1989). The preliminary estimates were subsequently revised and finalized in the Draft State Energy Plan (May 1989).

[5] This percentage is derived by dividing the 1.405 ¢/Kwh externality cost by each IOU's levelized avoided cost. For example, assuming an IOU levelized avoided cost of 6 ¢/Kwh, the percentage of the externality cost to this avoided cost would be about 23 percent (1.405 divided by 6).

This paper provides some thoughts on the use of these approaches for more fully incorporating environmental externalities in New York's energy planning process. It is hoped that conclusions reached in this paper can be generalized for use in Canada.

PUBLIC UTILITY REGULATORY POLICY ACT

PURPA was adopted to encourage the development of cogeneration and small power production by establishing a general obligation for utilities to interconnect with a qualifying facility (QF) and to purchase energy from these facilities upon request. In New York State, utility long-run avoided cost (LRAC) estimates provide the basis for energy only payments to QFs and for capacity and energy payments to QFs under 2 MW.

The NYPSC is currently in the process of updating the State's IOU LRAC estimates.[6] There are two important shortcomings in the LRAC estimates prepared by the New York Power Pool (NYPP) for this proceeding, which are likely to hinder the economics of non-polluting renewable resource technologies. These are: the LRAC estimates do not account for the costs of complying with the Clean Air Act Amendments of 1990 (CAA); and the LRAC estimates do not account for environmental externality costs associated with underlying generation sources.[7]

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[6] NYPSC, Case 91-E-0237, Proceeding on Motion of the Commission to Establish Long-Run Avoided Costs Estimates Recognizing Bidding Auction Results (March 12, 1991).

Complying with CAA requirements for SO_2 and NO_x will require capital expenditures and increased fuel and operation and maintenance costs on the part of the New York utilities. Title IV of the CAA requires each utility to implement measures to meet its SO_2 emission allowances. Also, because New York is included in the Interstate Ozone Transport Region defined under Title I of the CAA, most fossil fuel-fired generation units are expected to be required to implement advanced control technologies for NO_x with control efficiencies of 80 to 85 percent. The capital and operation and maintenance (O&M) costs for these compliance measures should be included in the LRAC energy component, since these costs are "avoidable." A preliminary assessment indicates that the cost of CAA compliance for New York utilities ranges from about 0.1 to 0.4 ¢/kwh, depending on the characteristics and location of the individual utilities' plants.

The environmental externality costs associated with residual emissions from generation sources which underlie the LRAC estimates also represent avoided costs. Therefore, the LRAC estimates should also include an environmental externality cost component based on residual emissions.

In this paper, the environmental externality cost component is based on emissions of SO_2, NO_x and CO_2 from the electricity generation source(s) which operate on the

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[7] Some parties to the proceeding have called for the inclusion of these concerns. Therefore, it is possible that the final LRACs may address these concerns to some extent.

Table 2

LRAC Externality Cost Estimates Under Alternative Dollar Per Ton Externality Cost Assumptions (Nominal Levelized Costs)

Source	Dollar Per Ton Costs			Cents Per Kwh Costs[e]			
	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2	Total
NYPSC-Adopted:[a]	795	1,185	1.0	0.26	0.25	0.09	0.60
Draft 1991 SEP Update:[b]							
Trust Fund Tax[c]	280	1,405	7.9	0.09	0.18	0.70	0.97
General Revenue Tax[d]	1,274	6,081	107.0	0.42	0.80	9.43	10.65

a/ These are the implied \$/ton costs which are associated with the ¢/Kwh externality costs adopted by the NYPSC in 1989. The NYPSC-adopted externality costs for SO_2 and NO_x are based on costs developed by the SEO in a preliminary draft of the "Environmental Externality Issue Report" of the 1989 State Energy Plan (Feb. 24, 1989). These SO_2 and NO_x values were refined and finalized in the Draft State Energy Plan (May 1989). The NYPSC-adopted CO_2 externality cost is a judgmental value.

b/ These \$/ton externality costs were developed by the SEO and reported in the 1991 State Energy Plan Update, Issue 9: Energy and Environmental Taxes, p. 25.

c/ The Trust Fund externality costs assume that revenues are used to finance expenditures on pollution abatement measures, including energy efficiency and renewable resource projects.

d/ The General Revenue externality costs assume that revenues are used for general revenue purposes, increasing energy cost to the point where the desired amount of pollution abatement occurs by market forces.

e/ Externality costs in ¢/Kwh are based on the above \$/ton costs, assuming that the distribution of electricity generation on the margin is based on production costing modelling results for 1992 to 1999, reported in Niagara Mohawk's 1991 Demand Side Management Plan (date). The results of this report suggest that electricity generation on the margin consists of 54 percent oil, 16 percent coal and 30 percent natural gas. The emission rates (lbs/mmbtu) for these type of plants are: Oil plant: 0.32 for SO_2, 0.2 for NO_x, 169 for CO_2; Coal plant: 2.4 for SO_2, 0.57 for NO_x, and 220 for CO_2; and Gas plant: 0 for SO_2, 0.27 for NO_x, and 117 for CO_2.

margin.[8] Based on this premise, Table 2 presents estimates of the resultant ¢/Kwh LRAC externality costs for three alternative \$/ton estimates of SO_2, NO_x and CO_2: an estimate of the \$/ton costs underlying the NYPSC ¢/Kwh values; and estimates presented in the Draft '91 SEP Update based on the general revenue (GR) tax and the trust fund (TF) tax approaches. As shown in Table 2, the LRAC environmental externality cost component could range from 0.60 ¢/Kwh (NYPSC costs) to 10.65 ¢/Kwh ('91 SEP Update GR tax).

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[8] For illustrative purposes, the distribution of electricity generation on the margin is assumed to be based on production costing modelling results for 1992 to 1999, reported in Niagara Mohawk's 1991 Demand Side Management Plan. The results of this report suggest that electricity generation on the margin consists of 54 percent oil, 16 percent coal and 30 percent natural gas. The emission rates (lbs/mmbtu) for these type of plants are: Oil plant: 0.32 for SO_2, 0.2 for NO_x, 169 for CO_2; Coal plant: 2.4 for SO_2, 0.57 for NO_x, and 220 for CO_2; and Gas plant: 0 for SO_2, 0.27 for NO_x, and 117 for CO_2.

Estimates of CAA compliance are relatively small compared to estimates of air emission externality. Furthermore, a significant proportion of the New York State CAA compliance costs (60 to 100 percent) result from stringent NO_x controls likely to be required under Title I of the CAA, due to New York's inclusion in the Interstate Ozone Transport Region.[9] For most of the nation, stringent NO_x controls are not required which reduce the cost of CAA compliance and make externality costs an even more significant consideration than CAA compliance costs.

USE OF TAXES FOR CONSIDERING EXTERNALITY COSTS

Taxes provide a mechanism for internalizing externality costs, by providing market incentives to abate pollution, and by generating tax revenues which can be used for remediation of pollution. However, implementation of environmental taxes for the purpose of internalizing externality costs requires specifying the use of tax revenues (e.g., whether revenues are used for general treasury purposes or are earmarked for environmental improvement).

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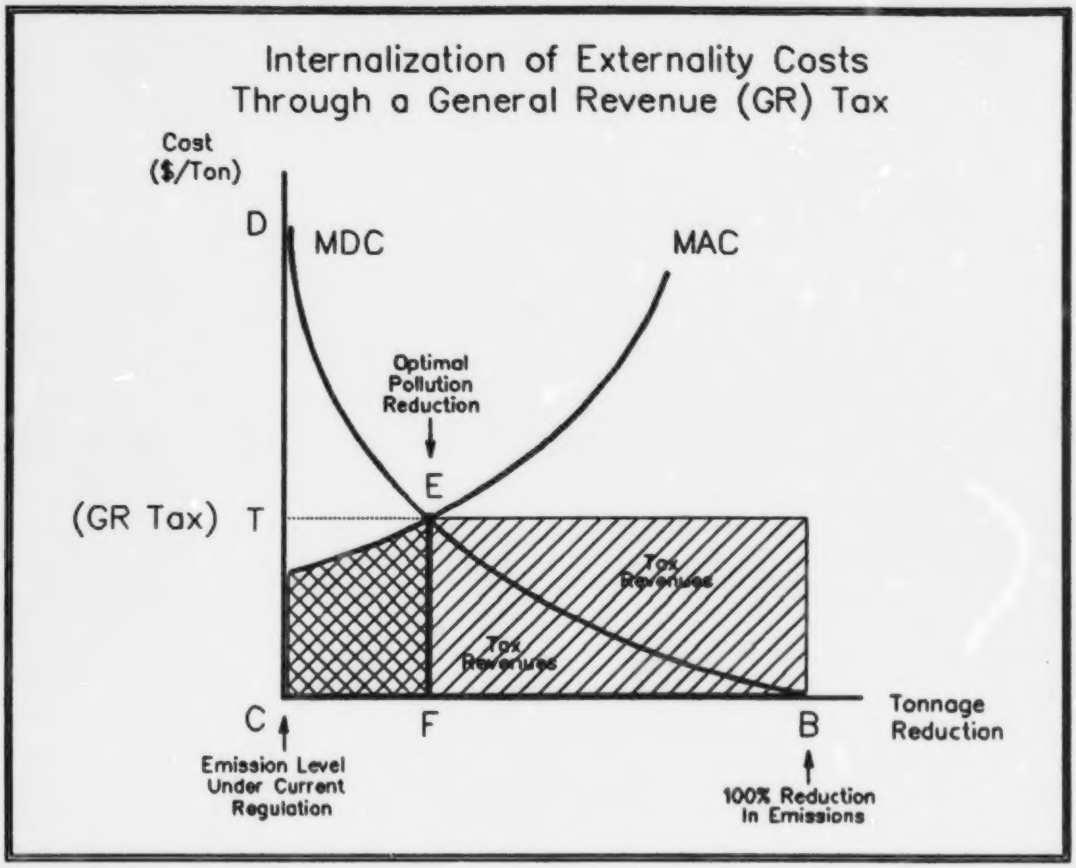
[9] NO_x controls comprise 100% of the total CAA compliance cost for utilities which have excess SO_2 allowances, such as Con Ed and LILCO. In fact, for these utilities, the NO_x compliance cost is greater than the total (net) compliance cost because credits have been assigned to represent the trading value of the excess SO_2 allowances.

When tax revenues are placed in government treasuries for general revenue purposes, the role of the tax is to reduce emissions by making products which cause pollution loading more expensive, thus encouraging pollution abatement and energy conservation. The tax rate which is consistent with this approach is the highest marginal cost of the abatement measures required to achieve the desired level of reduction. This is termed a general revenue (GR) tax, and is illustrated in Figure 1.

The optimal GR tax is defined by the intersection of the marginal abatement cost (MAC) and marginal damage cost (MDC) curves (corresponding to the optimal level of pollution abatement), and is shown as point T in Figure 1. If the environmental tax is set below T, market signals will not be sufficient to induce the optimal level of pollution abatement.

The cost to energy consumers in implementing this GR tax is equal to the cross hatched area plus the shaded area in Figure 1. The cross hatched area represents increased costs to energy consumers resulting from the tax-induced installation of pollution abatement measures by polluting sources. This level of abatement occurs because it is less expensive for sources to abate the pollutant over this range of reductions than to pay the

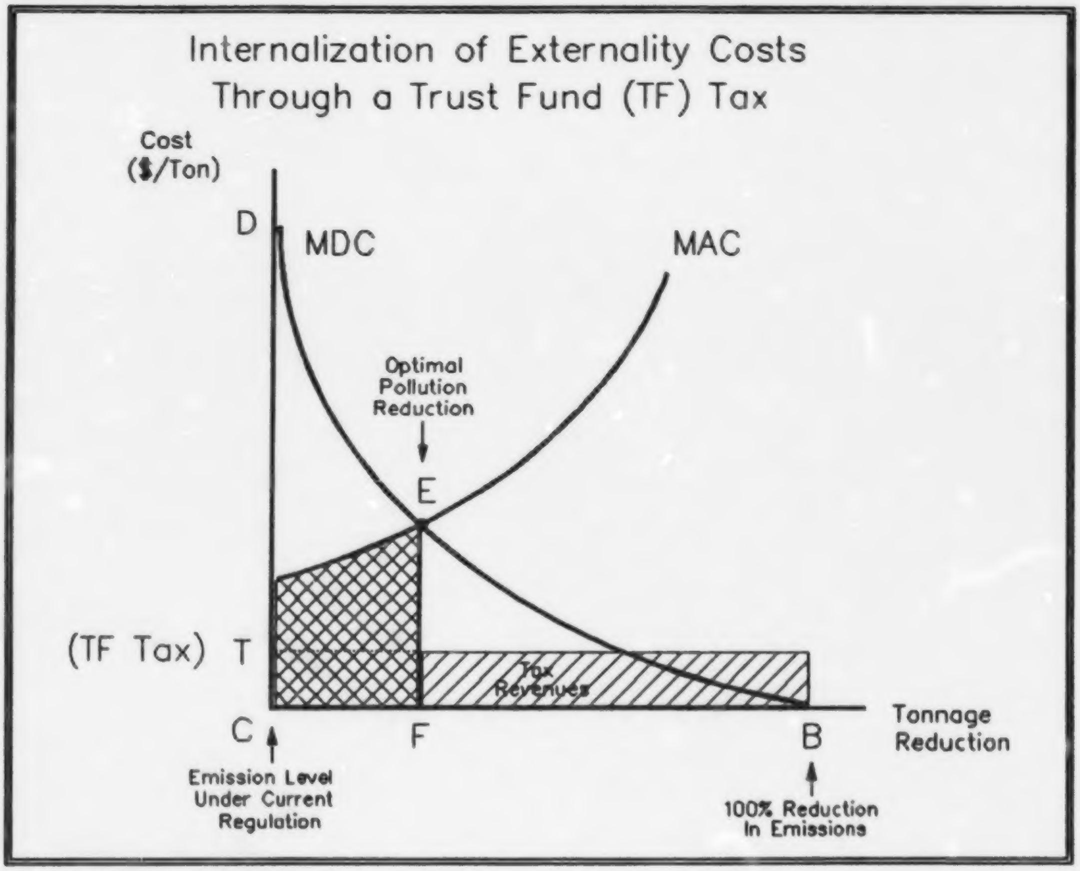
Figure 1



tax. The slashed area represents the revenues collected under the GR tax, being that it is less expensive for polluters to pay the tax rather than to abate pollution over this range of reductions.

When revenues from the environmental tax are earmarked for the purpose of remediating environmental externality costs (financing expenditures on pollution abatement measures including energy efficiency and renewable resource projects), the required tax rate will be lower than the GR tax. This mechanism is termed the trust fund (TF) tax and is illustrated in Figure 2.[10]

Figure 2



The TF tax is derived by distributing the total costs of the abatement measures required to achieve the optimal pollution reduction (the cross hatched area) over the tax base (the tons of pollution emitted assuming GR tax is implemented shown as FB). That is, the TF tax should generate revenues in the amount of the cross hatched area in Figure 2. Thus, the total cost to energy consumers is equal to the cross hatched area (total abatement cost) or the slashed area (tax revenues) since the two areas are equal by definition.

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[10] Most of the recent energy and environmental tax proposals have embodied the concept of a trust fund by requiring a portion of the tax revenues be earmarked for pollution abatement.

The GR tax mechanism could result in a higher compliance costs to energy consumers than the TF tax. The higher compliance costs arise primarily because of the additional revenues generated (e.g., the slashed area in Figure 1). The revenues collected could, of course, be returned to consumers, resulting in the net increase in costs being equal to just the cross-hatched area.[11]

While it is theoretically conceivable to redistribute the revenues back to energy consumers in order to mitigate the associated cost impacts, the acceptability and even "do-ability" of such an approach is questionable. For example, the imposition of a GR tax to internalize residual SO_2, NO_x and CO_2 externality costs is estimated to increase New York State average electricity rates by more than 30 percent in year 2000. Alternatively, imposition of a TF tax to achieve the same objective would increase electricity rates by only 3 percent.[12] Clearly a major difficulty in implementing the GR tax approach, is the political acceptability of imposing a 30 percent increase in the price of electricity on ratepayers, even though about 25 percent of this increase is to be refunded.

The distinction between how the GR tax approach and TF tax approach affect the development of wind electricity generation resources, is illustrated to provide further insight into the correct application of environmental externalities in energy planning. The illustration is based on analyses presented in the New York State report Analysis of Carbon Reduction in New York State.[13] The costs and mitigation potential of select abatement measures examined in the New York State study have been used to construct a carbon abatement cost schedule for New York, shown in Figure 3.

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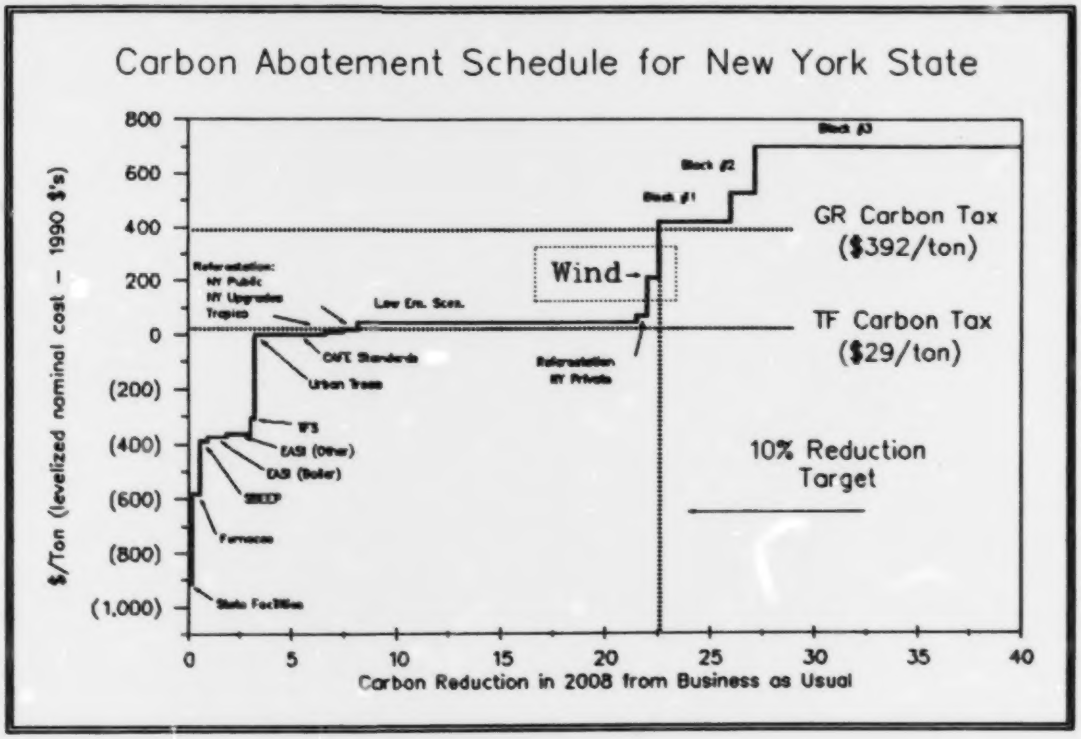
[11] An appropriate emission cap with tradeable emission allowances effectively achieves this result.

[12] Based on estimates presented in the Draft '91 State Energy Plan Update, "Energy and Environmental Taxes," Volume III, July 1991.

Figure 3



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[13] Analysis of Carbon Reduction in New York State. Prepared by the NYS Energy Office in consultation with the NYS Department of Environmental Conservation and the NYS Department of Public Service. June 1991.

Notes to Figure 3

All levelized $/ton costs include capital costs plus fuel savings, if applicable, over the life of the measure.

State Facilities - Assumes 20% reduction in energy use by 2000 (Governor's Executive Order).

Furnaces - Improvement of residential furnace efficiency from 81% to 91%.

SBEEP - Small Business Energy Efficiency Program; Provides on-site surveys geared to the needs of small commercial businesses and not-for-profit organizations.

EASI (Boiler) - Energy Advisory Service to Industry program; Provides on-site surveys to identify energy saving improvements. Available to small and medium sized commercial and industrial firms.

EASI (Other) - See #5 above; separate programs available for all other systems except boilers.

TFS - Technical Feasibility Studies program; Offers matching funds for analyses of energy conservation projects. Available to small and medium industrial, commercial and agribusiness firms.

Urban Trees - Planting trees to provide shade and reduce air conditioning use.

CAFE Standards - Increased average fuel mileage from 28 mpg in 1988 up to 42 mpg in 2000.

Reforestation - Four measures: tropical reforestation, upgrading of NY forests, reforestation on NY public land, reforestation on NY private land.

Low Emissions Scenario - Electricity supply planning scenario which employs increased natural gas use, reduced coal and oil use, and increased DSM - i.e., reduced need for new capacity. Includes difference in revenue requirement from Reference Scenario and customer share of DSM costs.

Wind - Assumes 1200 MWs of wind capacity operating at 15% capacity factor replaces existing coal generation.

Block #1 - Could include any number of new technologies which affect energy supply or demand; cost and impact estimated by proxy. Assumes that all new utility-owned coal generation capacity required by 2008 (2,500 MWs of AFB Coal) is replaced by hybrid generation units consisting of photovoltaics (PV) backed up by high-efficiency gas combustion turbines (the back-up is required because the PV's would operate at only 30% capacity factor, while the AFB replaced would operate at about 80%). Gas price assumed to double because of supply constraint.

Block #2 - Estimated by proxy (see above note). Assumes that 25% of existing coal capacity is retired early and replaced by the hybrid PV and gas turbine units described in Block 1.

Block #3 - Assumes that remainder of carbon reduction required to reach 20% objective could be achieved at $500/ton. Assumes that societal demand for carbon reduction facilitates development of new technologies and associated carbon reductions. Reductions could occur in electricity generation (supply or demand side), transportation, residential, commercial or industrial sectors. As the cost for this block is conceptually a weighted average of many individual measures, some of these measures (e.g. biomass generation, additional DSM or reforestation, etc.) could come in at costs much lower than $500/ton while others (e.g. additional renewable resources) could be higher. Also, a portion of this block of carbon reduction could result from reduced energy use due to price increases.

The GR tax required to achieve a 10 percent reduction in New York State carbon emissions is estimated to be on the order of $392/ton of carbon (or $107/ton of CO_2). In addition, cost of wind resources (as a carbon abatement measure) are estimated at about $219/ton (or $60/ton of CO_2). Given these results, Figure 3 indicates that a carbon tax of $392/ton would encourage the development of wind generation since wind resources are less costly on a $/ton basis than the GR tax.

Taking the analysis another step, at the GR tax level ($107/ton CO_2) the corresponding CO_2 adder for New York's LRAC estimates on the order of 9.43 ¢/Kwh (as shown in Table 2). Clearly an adder of this magnitude will greatly enhance the development of wind and other clean renewables.

Alternatively, a trust fund tax of about $29/ton of carbon ($7.9/ton of CO_2) would be required to achieve a 10 percent reduction in New York State carbon emissions, provided the tax revenues are earmarked to fund carbon abatement measures. Referring to Figure 3, it is clear that a carbon tax of $29/ton does not provide sufficient price incentive to encourage the development of wind resources, since the tax rate is well below the cost of wind resources. However, the trust fund approach requires that a portion of the revenues be specifically earmarked for developing wind energy resources, since wind is a component of the least-cost mix of abatement measures required to achieve a 10 percent reduction in carbon emissions, as shown in Figure 3.

Environmental adders for CO_2 emissions in competitive bidding and LRAC proceedings which are based on the TF tax would only be on the order of 0.7¢/Kwh (as shown in Table 2). Such adders may not significantly improve the economics of wind energy projects over fossil fuel generation alternatives. But adders based on TF approach should not be used since these adders do not result in revenues which can be used for pollution remediation. Given that the use of adders is only for ranking projects, they must be based on GR taxes.

POLICY FOR RENEWABLES

Consideration of environmental externalities in energy planning is important for improving the economics of renewable resources. In the absence of environmental taxes or fees, there is a need to exogenously consider externality costs in energy decision-making through an environmental adder approach.

Environmental adders should be based on a GR tax of the type estimated in the Draft '91 SEP Update,[14] so that they induce a similar affect as a general revenue tax. The GR tax externality costs estimated in the Draft '91 SEP Update are considerably higher than those currently used by the NYPSC. The use of GR externality costs will result in greatly improving the economics of clean renewable resources.

A short coming of environmental adders is that they only provide a partial mechanism for the internalization of externality costs. The foremost reason is that environmental adders, unlike the general revenue tax or trust fund tax approaches discussed in this paper, do not require the collection of an environmental tax or fee in the amount of the environmental externality cost. Thus, the adder is not likely to induce changes in the environmental characteristics (emissions) of competing resources causing the adders to be an ineffective means of achieving a particular environmental goal.[15] In other words, if emissions from each competing source are considered socially excessive, the adder approach does not provide an incentive for the remediation of these emissions.

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[14] Draft 1991 State Energy Plan Update, "Energy and Environmental Taxes," Volume III, July 1991.

Any serious attempt to internalize the externality cost in energy planning decisions, should require that producers be presented correct price signals derived from externality costs being included in energy prices through taxes or fees. This will obviate the need for administering the selection and use of environmental adders in utility competitive bidding programs and calculation of LRACs.

With regards to clean renewables, either tax approach should be conducive to their development. That is, the GR tax will inherently provide clean renewables with a large price advantage (through a large environmental adder) over fossil fuel generation sources. Alternatively, if the TF tax approach is used, funding for clean renewables will be an integral part of the tax package.

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[15] The environmental adder approach also does not mimic the existence of a emissions cap (with marketable permits).

Global Warming has become an important international issue. The European Community countries are calling for reductions in CO_2 emissions to address this issue. There is a great pressure on the U.S. to set a target for reducing its own CO_2 emissions. This could result in adoption of a federal carbon tax some time in the near future.[16]

Since, a TF tax is based on lower tax rates, resulting in lower costs to energy consumers, the TF approach is becoming more popular among policy-makers the general revenue approach. In fact, a draft bill in the US Senate, "The Sustainable Energy Transition Act of 1991", proposes that revenues from a federal carbon tax be placed in a Trust Fund and allocated to the states to finance renewable resource and energy efficiency projects.[17] The proposed carbon tax would be phased in over a two year period, starting at approximately $1.30 per ton and increasing to approximately $4.00 per ton of carbon.

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[16] A carbon tax would also function as a general green tax, causing reductions in SO_2, NO_x and other air pollutants as well as carbon. For example, it is estimated that a $5/ton federal carbon tax is estimated to reduce New York's carbon emissions by about 900,000 tons, and emissions of SO_2 and NO_x by about 20,3000 tons and 7,500 tons, respectively.

Enactment of a federal carbon tax may be one of the most important factors in improving the economics of clean renewables in comparison with fossil fuel alternatives. However, pending the adoption of a federal carbon tax, the use of environmental adders in IOU competitive bidding programs and in estimating LRACs should be based on a GR tax externality cost.

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[17] The European Commission has recently proposed an energy/CO_2 tax which translates to over $20 per ton carbon tax. Such a proposal has been endorsed in principle by both EC finance ministers and environment ministers.

In addition, the Draft '91 SEP Update recommends that the State should "support enactment of a phased in federal carbon tax with revenues earmarked for states to fund environmental improvement and pollution remediation programs and projects, including energy efficiency and renewable energy resource programs." The American Wind Association has indicated its support for this recommendation in its comments, stating that:

> "We ... endorse the staff's recommendation that the state support a federal carbon tax. There is much in staff's discussion ... that is a valuable contribution to the public debate, and New York is to be commended for it."

Similarly, the National Academy of Sciences, in a recent report, supports the general concept of a carbon tax in stating the following:

> "On the basis of principle that the polluter should pay, pricing of energy production and use should reflect the full costs of the associated environmental problems. The concept of full social cost pricing is a goal toward which to strive."

EXPERIENCE OF THE NORTHWEST POWER PLANNING COUNCIL IN ADDRESSING ENVIRONMENTAL ISSUES IN ELECTRIC POWER PLANNING

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The U.S. Pacific Northwest, consisting of the states of Idaho, Montana, Oregon and Washington, is served by an integrated electric power system. This system comprises nearly 38,000 megawatts of installed capacity. Annual firm energy loads are about 19,600 average megawatts (172 x 10^3 GWh/yr). This system is integrated with the electric power systems of the U.S. Pacific Southwest and western Canada.

The existing resource base of the Pacific Northwest is dominated by hydropower. Hydropower supplies about 75 percent (29,600 megawatts) of regional generating capacity and, on average, about two thirds of the electric energy (firm and non-firm) used by the region (about 16,400 average megawatts (143 x 10^3 GWh/yr)). About 95 percent of the region's hydropower is obtained from projects located on the Columbia River and its tributaries. The balance of the electrical energy used by the region is obtained from coal, nuclear, natural gas, and biomass resources and interregional energy exchanges and imports.

THE NORTHWEST POWER PLANNING COUNCIL

The Northwest Power Conservation and Planning Council, established in 1981, is a regional planning and policy-making organization. The eight-member Council is composed of two representatives from the states of Idaho, Montana, Oregon and Washington. The Council maintains small state offices and a central office of about forty staff in Portland, Oregon.

The Council is responsible for preparing a strategic regional electric power plan, a program of measures for the protection, mitigation and enhancement of the fish and wildlife resources of the Columbia River system, and a program for involving the public in regional electric power and fish and wildlife issues.

The Council's Pacific Northwest Conservation and Electric Power Plan includes a 20-year forecast of regional electric power needs, an assessment of resources available to meet future electrical needs, and an action plan for meeting future electrical needs in a cost-effective and environmentally-sound manner. The action plan provides guidance for the Bonneville Power Administration, regional utilities, regulatory agencies and other decisionmakers involved with the Northwest electric power system.

The objective of the Columbia River Basin Fish and Wildlife Program is to protect, mitigate and enhance the fish and wildlife and related spawning grounds and habitat of the Columbia River and its tributaries. The program contains recommendations affecting stream flows, fish passage, harvest, propagation, fish and wildlife habitat and other factors affecting anadromous and resident fish and wildlife. The program is implemented by the Bonneville Power Administration (A federal wholesale power marketing agency serving the Pacific Northwest), regional utilities, resource management agencies and others.

PROVISIONS OF THE NORTHWEST POWER ACT - THE GROUND RULES

Actions of the Council are governed by the Pacific Northwest Electric Power Planning and Conservation Act (Regional Act), an act of Congress. Among the principal objectives of the Regional Act are the development of cost-effective energy conservation and the encouragement of the development of renewable energy resources. A major factor leading to the emphasis given these resources in the Regional Act is the environmental attributes of these resource types.

A key feature of the Regional Act is the inclusion of conservation measures in its definition of new electric power resources. Conservation is defined as reduction in electric power consumption as a result of increased efficiency of energy use, production or distribution. Measures that improve end-use, distribution and transmission efficiency qualify, as do measures that reduce internal generating plant loads. Reduction of amenity does not constitute conservation.

The Regional Act directs that new resources are to be selected on the basis of cost-effectiveness. Cost-effectiveness means the resource is reliable and available within the time it is needed; and has a system cost no greater than competing resources. System cost includes all direct lifecycle costs, costs of transmission and distribution where applicable, and environmental costs and benefits, where these have been quantified.

Conservation is to be given priority in meeting future loads. The Regional Act stipulates that conservation measures be given a ten percent credit over generating resources when assessing cost-effectiveness. Among equally cost-effective resources, priority is to be given first to conservation, second to renewable resources, third to generating resources utilising waste heat or of high fuel conversion efficiency, and fourth to all other resources. Because actual conservation or generating projects are seldom of equal cost-effectiveness, the resource priorities of the Regional Act serve more for policy guidance than for selecting projects for acquisition.

INCORPORATING ENVIRONMENTAL CONSIDERATIONS INTO THE COUNCIL'S PLANNING AND POLICY DEVELOPMENT

The Council has used diverse approaches for incorporating environmental considerations into its planning and policy development. Methods that the Council has employed to address environmental concerns include cost-effectiveness premiums for conservation measures; resource acquisition criteria; research, development and demonstration for priority resources; and changes to the design and operation of the existing power system.

Cost-effectiveness Premiums

The ten percent cost-effectiveness premium accorded by the Regional Act to conservation measures reflects the attractive qualities of conservation, in comparison to generating resources. These include low cost, minimal environmental impact, small module size and short development lead time. The value of these qualities is not fully incorporated into conventional economic analyses.

The Council's assessment of new resource options suggests that attributes of conservation not normally captured in economic comparisons of resources are even greater than the ten percent premium of the Regional Act. Through system modelling techniques, the value of some of these attributes, including short development lead times and coincidence of conservation savings with load growth can be incorporated into the Council's quantitative analysis of resource cost-effectiveness. But, additional, difficult-to-quantify values of conservation, such as lack of significant environmental impact and the benefits of public acceptance remain unaccounted for. For these reasons, the Council, in its current Power Plan has added an additional 20 percent to the ten percent conservation premium of the Regional Act.

The regional lifecycle avoided costs for new resources is about 7.7 cents per kilowatt-hour (nominal 1990 U.S. dollars). Avoided transmission and distribution costs and losses, the ten percent credit of the Regional Act, and the Council's additional 20 percent premium brings the avoided cost limit of conservation to to 11 cents per kilowatt-hour. The overall conservation premium of the 1991 Power Plan exceeds 30 percent.

This premium was not arrived at by rigorous quantitative analysis. Some advantages of conservation in comparison with other resources are too complex and subtle to support quantitative analysis. Instead, the Council arrived at the additional premium by judgemental means, confirmed through a public review process.

The Council has not established premiums for any generating resources. Though differences among generating resources may not be fully reflected in the economic cost estimates for these resources, the diversity among and within generating resource types, difficulties of applying single value premiums to generic classes of resources and a desire to emphasise conservation has led the Council use other approaches to address environmental concerns relating to generating resources. Some of these approaches are described below.

Resource Acquisition Criteria

Environmental impacts of energy projects often can be mitigated through site selection, design and operational procedures. This is recognised in regulations such as the new and existing source performance standards, ambient air quality criteria and emission caps established by the U.S. Clean Air Act and subsequent amendments.

Existing regulations, however, may not achieve the desired level of environmental control. This can occur when the political system has not had time to react to a new problem or increasing public concern relative to an existing environmental effect; because general public concern has not been raised to a level resulting in political action; because local sensitivities are greater than those of the entity responsible for regulation; among other reasons. In several cases, the Council has developed specific resource acquisition criteria for avoiding or mitigating potential environmental impacts not falling within existing governmental regulation.

Two examples of resource acquisition criteria that have been established by the Council include are indoor air quality standards for energy-efficient buildings, and siting criteria for hydropower development.

> Indoor Air Quality: Reduction in air infiltration is an important measure for improving building energy-efficiency. But infiltration reduction can lead to unacceptable levels of pollutants originating within the confines of the building. To ensure acceptable indoor air quality within energy-efficient buildings, the Council's model conservation standards require pollutant source control, pollutant monitoring, and mechanical ventilation to achieve indoor air quality as good or better than for buildings constructed with standard practice prior to the adoption of the model conservation standards.
>
> Hydropower Siting Criteria: Several thousand megawatts of hydropower potential remains undeveloped in the Northwest. Hydropower development can severely impact water quality, streamflows, land use, fish and wildlife. Important aesthetic, recreational and cultural river values can be affected. Of particular concern in the Northwest are impacts on anadromous fish species. These once-abundant fisheries have been severely depleted by hydropower development, fishing, logging and grazing.
>
> To provide guidance for future hydropower development in the region, the Council, working with the Northwest states, has designated certain stream reaches as protected areas. New hydropower development is generally prohibited within these reaches. Protected areas are intended to protect fish and wildlife resources and send a clear signal to developers regarding the acceptability of stream reaches for hydropower development. They also facilitate estimating the availability of new hydropower and provide guidance for hydropower licensing decisions by the Federal Energy Regulatory Commission.

Confirmation of Priority Resources

A third approach used by the Council to incorporate environmental considerations into the future Northwest electric power system is through research, development and demonstration intended to improve the availability, reliability and cost-effectiveness of promising renewable resources. Because these resources are expected to have few environmental impacts, resolution of impediments to their development through research, development and demonstration activities should reduce the environmental impact of the future power system.

To develop research, development and demonstration recommendations, the Council convened an Renewable Resources Research, Development and Demonstration Advisory (RD&D) Committee. This committee, consisting of representatives of utility, government, research and public interest groups, was charged with developing research, development and demonstration agendas for resolving impediments to the development of geothermal, wind and solar resources. Each of these resources are thought to have good potential in the Northwest.

The RD&D Advisory Committee, with the assistance of resource experts, identified activities that should be undertaken to help being these resources to the point where they can be readily developed as they become cost-effective. These recommendations include additional resource characterisation, identification and resolution of environmental concerns and demonstration projects.

After achieving general agreement concerning the draft recommendations, the Committee prepared an issue paper for broad public comment. Following review and consideration of public comments, the Committee recommended geothermal, wind and solar confirmation agendas to the Council. The Council, with minor modifications, adopted the confirmation agendas into its 1991 Power Plan. Following release of the plan, the Council has been working with the Bonneville Power Administration, regional utilities, resource developers and others to implement the confirmation agendas.

Environmental Effects of the Existing Power System

Many of the projects in the existing power system were constructed when social attitudes toward the environmental impacts were generally more tolerant that at present. Though efforts at mitigation were made during initial development, increased environmental sensitivity and understanding, unanticipated environmental effects, and greater population and economic pressures on natural resources have, in cases, resulted in unacceptable environmental impacts from the existing power system.

The Council, through its Fish and Wildlife Program, is addressing environmental impacts of the Columbia River hydropower development. Of particular concern at present is preservation and restoration of several threatened and endangered species of anadromous fish native to the Columbia River basin.

The resolution of concerns regarding the anadromous fisheries of the Columbia River is an enormously complex problem, affecting the design and operation of the hydropower system and the diverse interests that benefit from the river. In addition to United States and Canadian utilities and electrical consumers, other affected groups include agriculture, transportation, recreation, foreign and domestic commercial fisheries and native Americans. Sacrifices will have to be made by all to achieve restoration of threatened species.

The process used by the Council to prepare plans and to develop policies for restoration of Columbia River fish and wildlife resources is one of first gathering basic information and recommendations from interested and affected organisations, followed by analysis and negotiation to arrive at draft plans and policies. These are circulated for public comment. After reviewing public comment and making appropriate modifications, the Council incorporates the recovery plans and policies into its fish and wildlife program.

Earlier agreements regarding the actions needing to be undertaken to protect, mitigate and enhance the fish and wildlife of the Columbia River were arrived at only following long and complex analysis and negotiation. These earlier efforts, though apparently improving the survival of Columbia River fish and wildlife, did not adequately protect species diversity. Protection of species diversity will require greater sacrifices among all river users. The success of current efforts to establish effective recovery plans remains uncertain.

CONCLUSIONS

The history of the efforts of the Northwest Power Planning Council to address environmental concerns resulting from current and future development and operation of the Northwest's electric power system provides several lessons.

First is the importance of achieving a consensus among affected interests. The Council, as an organisation with little direct authority, must rely on achieving consensus for the implementation of its plans and policies. Arbitrary or closed development of plans and policies is simply not acceptable to the public or the decisionmakers responsible for the regional power system and management of the Columbia River system. The Council's most successful efforts have been characterised by extensive involvement of affected organisations through advisory committees, consultations and public involvement efforts, coupled with sound technical information and analysis.

This leads to a second observation, the importance of good information and credible analysis. Much of the success of the Council in implementing its plan and policies can be attributed to the respect accorded the Council's analyses. This demands good data, extensive consultation with technical experts, state-of-the-art analytical tools and capable staff. These, coupled with the consensus-building efforts described above, have enabled the Council to create plans and policies commonly used as "reference standards" by organisations throughout the region whether or not these organisations are mandated to respond to Council policies.

Thirdly, is the need to consider diverse approaches to resolving environmental issues. As is evidenced by the sample of approaches discussed above, no single approach suffices for all issues. While the underlying theory of the recent interest in quantifying the full societal cost of resource development is sound, the complexity of real world environmental issues works against achieving accurate and accepted economic values for these environmental effects. Moreover, decisionmakers are skeptical of the validity of externality values, even for the single pollutants for which one might expect the greatest success in developing externality values. Generally, ad hoc issue analysis and negotiation, though time-consuming and messy, has been a more successful approach to addressing environmental concerns. This does not rule out further work on quantification of environmental externalities. The Council intends to monitor and participate in further development of these methodologies.

D:JK/LETTERS.BKS P

LUNCHEON ADDRESS

Monday, November 4

LUNCHEON SPEAKER:
Ian Goodman, The Goodman Group

Aboriginal Research Coalition
Externalities Associated with Energy Production: Types, Measures and Integration

Introduction

Externalities occur when the costs of actions are not paid by or their benefits not remitted to the individuals or corporations taking those actions. Externalities do not have costs or returns the actor can incorporate into his ledger, so they are largely ignored. Society frequently suffers as a result. While externalities have become almost synonymous with adverse environmental impacts, the correct definition is far broader and includes other costs such as traffic congestion, public service disruption or benefits such as employment and increased tax revenues. This report will concentrate on environmental externalities (costs), briefly cover other externalities, and discuss methods for incorporating both into energy planning.

Economists have been trying to evaluate and incorporate environmental externalities into policy making for many years, but have been frustrated by a lack of information, limited public understanding and the resistance of both environmental and business interests. Over the past two decades, however, two things have happened: first, much more information has become available regarding the effects of environmental damages on resources and resource uses, and second, economic approaches have gained influence in regulatory development as other approaches have faltered, particularly in water quality, air quality, hazardous waste and energy planning. The most notable example of codified externality valuation is the resource damage assessment process developed in the U.S. hazardous waste cleanup regulations (CERCLA[1]) a modified form of which also applies to marine oil and chemical spills (marine resource damage assessments) (CWA[2])(43 CFR[3], Subtitle A; Grigalunas and Opaluch, 1988; Kopp & Smith, 1989)

Economists must rely on information gathered by biologists, health professionals, physical scientists, statisticians and engineers to develop externality values. Through work by scores of economists, a system has evolved to allow approximations of market values. The system involves following a cause and effect sequence for each environmental disturbance through to a quantifiable change in an end resource use[4]. Figure 1. illustrates one variation of this sequence.

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[1] Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended (42 USC 9601)

[2] Clean Water Act (33 USC 1251-1376)

[3] Code of the Federal Register (U.S.). Where all U.S federal regulations are codified.

Figure 1. Externality Valuation Process

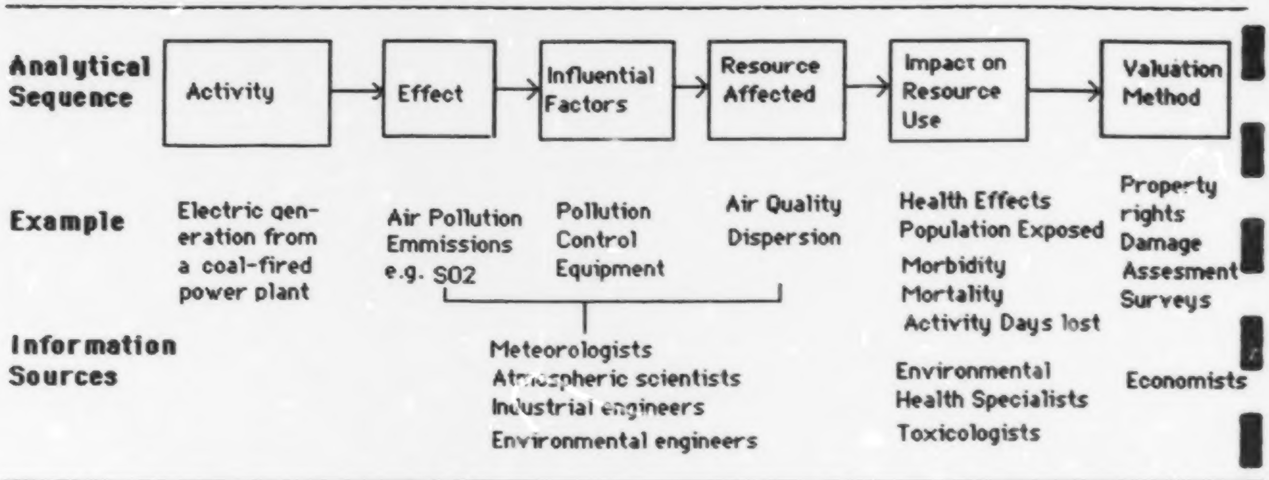
Analytical Sequence
Activity
Effect
Influential Factors
Resource Affected
Impact on Resource Use
Valuation Method
Example
Electric generation from a coal-fired power plant
Air Pollution Emmissions e.g. SO2
Pollution Control Equipment
Air Quality Dispersion
Health Effects
Population Exposed
Morbidity
Mortality
Activity Days lost
Property rights
Damage Assesment Surveys
Information Sources
Meteorologists
Atmospheric scientists
Industrial engineers
Environmental engineers
Environmental Health Specialists
Toxicologists
Economists

Figure 1 shows only one effect for one emission. Each activity often has several emissions or environmental impacts and each impact may have several effects on resources and resource uses. Estimation of total external costs for a proposed facility includes summing all the damages associated with all pollutants, plus other related damages such as construction-related mortality and injury. The process depicted in Figure 1 presumes understanding and identification of each of the following series of linked steps:

1. Activity: the activity that generates pollution or environmental damages; in the example, the activity in Figure 1 is coal combustion to produce electricity, which produces incidental adverse effects;

2. Effect: the levels or degree of effects which cause environmental damages, Figure 1 cites emissions of sulfur dioxide (SO_2). (other pollutants, from a variety of sources include nitrogen oxides (NOx), carbon dioxide (CO_2), radioactivity, particulate matter, etc.). Effects from other electricity sources include flooding, blockage of fish passage by dams, hot water discharge from nuclear plants, etc.

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[4] There are alternatives methods that require less information (discussed below); however, they are inferior and hopefully, will be phased out in favor of damage assessment.

3. Influential Factors: the measures which are or can be employed to influence the levels of the effects described above. In Figure 1, the example is pollution control equipment (scrubber to reduce SO_2 emissions). Influential factors for other generation types include fish ladders, stream flow regulation, and cooling towers.

4. Resources Affected: the resources affected by the activities and the degree and extent to which they are affected. This would include knowledge of the concentration of air pollutants as well as the distance and direction in which these pollutants are dispersed (Figure 2). Examples for other generation sources are: areas and habitat types inundated by dams, degree of fish use of inundated stream stretches, effect of inundation on fish populations, changes in fish species composition, changes in the fish themselves (such as higher flesh content of mercury), etc.;

5. Impacts on Human Resource Uses[5], the use of the affected resource (air) in the example is respiration. The complete measure of impact considers the number of people breathing emissions, and resultant affects on health. Examples for other generation options include: water consumed, fish caught, navigation, or river rafting[6]. These measures often rely on statistical analysis and extrapolation from other areas because direct measures are unavailable. Calculation of health effects would involve estimates of exposure to pollution (e.g. size of population exposed x duration of exposure x statistical estimate of mortality (deaths/million exposed/duration). An important component is the probability or risk of exposure. Some environmental impacts are chronic (high probability of occurrence) with a low cost (heated cooling water from fossil and nuclear energy facilities), others can be extremely rare (low probability), but with a high cost when they occur (dam failures, catastrophic radioactive releases, e.g., Chernobyl). Measures of change include morbidity (increased illness) and mortality (death), fish caught, recreation days or activity days;

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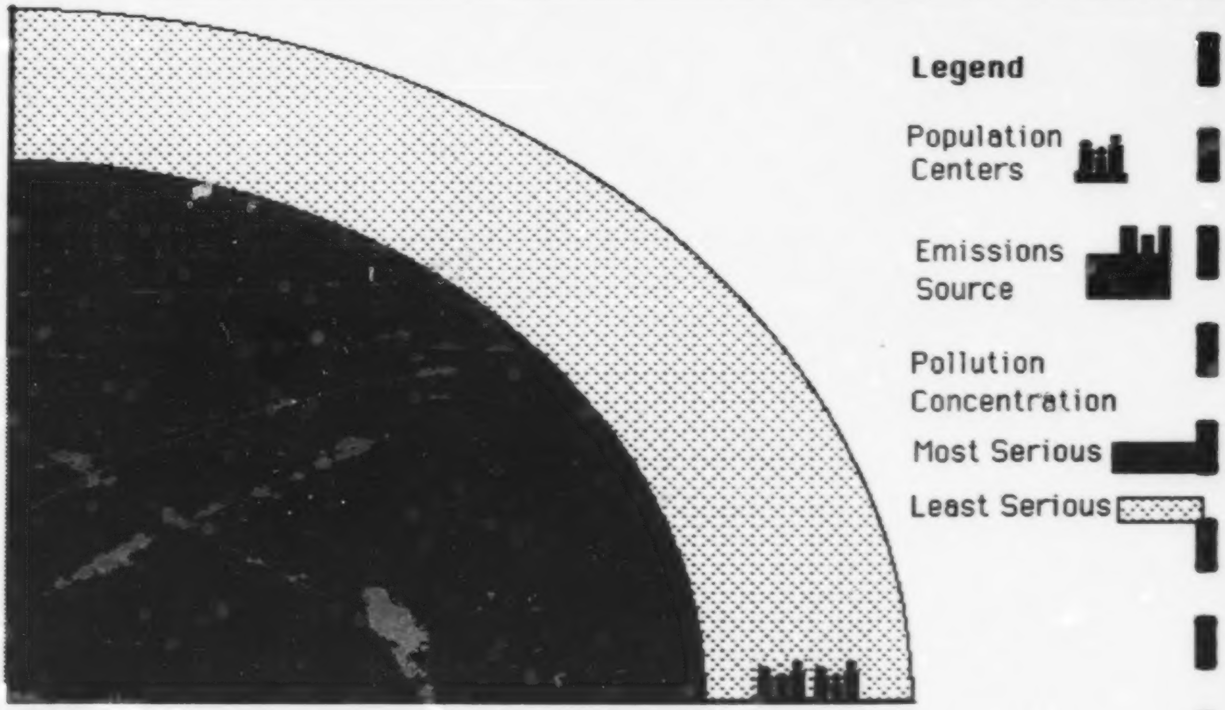
[5] The limitation of economic valuation to human uses is controversial. Economics is the study of human preferences as revealed by the choices people make. Except insofar as people have a preference for better treatment of animals and their habitat, and reveal this through market or political actions, economics ignores the issue.

[6] Economists have a broad definition of "use" Use of an environmental resource can include breathing or dumping toxic substances (to use extreme examples).

6. the values humans place on the use of the resources. The values obtained through this process are a function of resource "ownership", cultural values, and methods of calculation. This report focuses on the issues associated with how people value different types of externalities and how economists place monetary estimates on these values.

Figure 2. Air Pollution Dispersion and Populations Affected[7]


Legend
Population Centers
Emissions Source
Pollution Concentration
Most Serious
Least Serious

General Considerations in Estimating External Costs

Property Rights

To properly value externalities, it is important to understand who uses the resources involved and who has the rights to use them. With most commodities, ownership rights are well established and transfer of ownership takes place at market prices. The environment is different for reasons which will not be explored here. Unfortunately, in virtually no nation has the legal right to the environment been fully identified. Possession of rights to use the environment determines who gets to establish the values. The two general measures of establishing value used by economists are willingness to accept compensation, for those that own the environmental rights, and willingness to pay, for those who do not. The compensation measure is always equal to or greater than, in value per unit of the environment, the willingness to pay measure. Unlike the compensation measure, willingness to pay is constrained by the ability of people to pay for the environmental resource as well as the rest of the things they need or want.

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[7] Where pollution concentration is greatest the cost per person exposed is greatest. The few people near the power plant may suffer equal or greater total damages than the many people more distant. Valuations must consider both population size and exposure to health risks in each locale and sum over all areas exposed.

In a task that may never be finished, legislatures and judiciaries in many countries are slowly establishing who owns the environment. Fairness and fundamental rights play a big role in establishing environmental rights; for example, the right to breathe non-toxic air is generally considered a high priority right. Further changes in environmental rights have evolved through regulation, mostly giving the public, through the government, stronger rights to clean environments. The significance of this to externality valuation is that stronger rights increase the values placed on environmental resources, because the compensation value is higher.

Effects and Values of Electricity Generation

A variety of measures have been derived for valuing the various externalities associated with energy production. Appendix 1 lists some externalities by generation source. The following sections concentrate on how the damages are quantified and valued differently by economists and others. A brief mention of the effects of electric generation will be given here - enough to provide a framework for analysis. It is important to note that valuation does not imply that resources will be sold at the estimated values; a market does not exist for the externalities, which is why these valuation methods are necessary.

The effects of electricity generation differ with generation source, technology and location. A completely accurate assessment of effects on resources and use should therefore be site-specific. However, a site-specific analysis for every generation source, pollutant and resource use is infeasible, so general statements about each generation type may (and must) be made in order to compare and evaluate sources.

Air Emissions

Combustion-based fossil-, biomass- or municipal solid waste (MSW) plants generally emit more air pollution per kWh than nuclear or hydraulic alternatives, although nuclear has the potential for radioactive emissions. The major combustion air emissions are sulfur dioxide (SO_2), oxides of nitrogen (NOx), carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4) chlorinated fluorocarbons (CFCs), particulate matter (PM, or PM10 for materials less than 10 microns in diameter), volatile organic compounds (VOCs), and airborne toxics (metals or organic compounds).

SO_2

SO_2 contributes to acid deposition, corrodes masonry and metal structures, indirectly causes respiratory ailments through the formation of sulfate particles, and impairs visibility. In electricity production, SO_2 is principally controlled with flue gas desulfurizers (FGDs or scrubbers), sorbent injection and switching to fuels with lower sulfur content.

NOx

NOx contributes to acid deposition, causes tropospheric (low altitude) ozone build-up and generates photochemical smog which kills vegetation, is linked to cancer, causes respiratory ailments, and may promote global warming by limiting plant uptake of CO_2. Tropospheric ozone (as opposed to stratospheric ozone, which we need to filter out harmful ultra-violet rays) build-up is a serious health threat, particularly to people with pre-existing respiratory ailments (OTA, 1989). Selective catalytic reduction (SCR), steam or water injection and low NOx burners are the principal technologies for controlling NOx emissions from utilities.

Greenhouse Gasses (GHGs)

CO_2, CO, CH_4 , and CFCs[8] are the primary greenhouse gasses (GHGs), although NOx also contributes to global warming. The GHGs contribute to global warming by trapping solar radiation in the earth's atmosphere, which will eventually cause climate change. CFCs[9] additionally deplete the earth's protective stratospheric ozone layer, which allows more harmful ultra-violet radiation to reach the earth's surface. Stratospheric ozone depletion not only may contribute to global warming, but kills plants, interferes with food chains and increases skin cancer (Pace, 1990).

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[8] Recent evidence suggests the role of CFCs in global warming may not be not as great as previously thought (New York Times, October 24, 1991)

[9] CFCs are released by some chillers (commercial building-sized air conditioners) and by foam insulation, so are a consequence of DSM, although perhaps a short-lived one, due to an international phase-out of these compounds. Their replacements, HCFCs, are not nearly as damaging and will also be phased out eventually.

CO_2, the principal GHG, (50% of the global warming potential) is primarily (70%) produced by utility fossil fuel combustion (and is its most significant emission, by weight), although other forms of combustion and even hydraulic generation also increase CO_2 levels (NYSEO[10], 1991). Flooding increases global warming by eliminating vegetation that would sequester CO_2, and releases both CO_2 and CH_4 from inundated vegetation.

There is no question that the buildup of GHGs is contributing to global warming; the relevant questions for valuation are how fast, by how much and to what effect? Global warming may have a negative effect, a positive effect or be neutral, depending on what happens and where people live. Possible consequences are:

1. pronounced sea-level rise, (.3 to 1.5 meters), with inevitable loss of life and tremendous costs to prevent flooding;
2. major climate changes with increasing temperatures, and moisture variations - possibly very wet to very dry; some have even suggested a net cooling effect as more water vapor is in the atmosphere.
3. improvement or devastation of agricultural and forest production, (likely to be some of each in different locales).

Most scientists believe the net effect of global warming will be adverse, although a respectable minority believe mankind will adapt. (Neither humans in low-lying areas, nor animals and the natural environment may be so fortunate.)

Given the potential severity of adverse consequences, it seems prudent to avoid or counteract global warming, where possible. The principal ways to deal with global warming are to avoid activities which increase it: burning carbon-containing material, eliminating vegetated areas or increasing methane generation. Another way is to plant trees where none currently exist to sequester carbon in wood. A final (and currently uneconomic) method is the use of carbon scrubbers at fossil fuel plants and container storage of carbon. The sheer magnitude of carbon generated by fossil plants currently makes carbon storage infeasible. For example, per mmbtu of energy, a typical coal-fired plant emits 1.8 lbs of SO_2, 0.6 lbs of NOx, 0.15 lbs of particulates and 209 lbs of CO_2.

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[10] New York State Energy Office

VOCs

VOCs, when exposed to sunlight, contribute to the formation of ozone and photochemical smog, which cause respiratory ailments. VOCs are produced where liquid and gaseous fossil fuels are exposed to the atmosphere. Where fuels are adequately stored and completely consumed, few or no VOCs are released. The most common sources are fuel storage or transfer locations. VOCs tend to be a minor and local concern in electricity production and are principally controlled through vapor-recovery systems

PM, PM10

Particulate matter (ash, dust, etc.) is a combustion by-product that causes soiling of natural and man made environments, eye irritation and respiratory illness, corrosion and damage to plants and animals. Particulate matter can also bind and carry acids and toxics to various environmental receptors, as particles settle out of the air. Toxic substances bioaccumulate through the food chain or, in concentration, cause direct harm to living organisms. Particulates and toxics are mostly controlled through the use of fabric filters (baghouses), electrostatic precipitators, or both, in combination.

Radioactive Releases

Radioactive releases from nuclear power plants are of two types, routine low-level releases from operation, and catastrophic accidental emissions. It is not clear what the effects of the former are, although health may be adversely affected over time. The effect of the latter is drastic and costly, fortunately catastrophic releases are rare.

EMF

A final type of air pollution is electro-magnetic fields (EMF), from transmission lines, transformers or any electric device. EMF might as appropriately be classified with land-based pollutants because its effect is directly related to the size of the current, diminishes rapidly with distance from sources, such as power lines and transformers, and primarily affects land uses. EMF is strongly linked to cancer and other diseases in humans and may adversely affect wildlife in a variety of ways (Milham, 1985). EMF passes unimpeded through virtually all substances. The method of control for EMF is to minimize high current lines and keep people and animals distant from them.

Control Effectiveness and Costs

The control measures mentioned remove varying degrees of the pollutants from the air but none remove all the pollutants. The incremental cost per unit, or marginal cost, of controlling emissions increases with the percentage of emissions controlled (see Figure 3). Below certain threshold levels, some of these substances produce few or no adverse environmental effects, so it is not worthwhile to control all of the pollutants emitted. Figure 3 illustrates how marginal (additional) control costs increase and marginal damages decrease as the amount of pollution control increases (emissions decrease). Society is best off when marginal damages just equal marginal costs of control (E in Figure 3), or the point of equilibrium. At any point other than E, more can be gained than lost by moving to point E.

The concept of social equilibrium is important for externality valuation, because control costs provide a backdrop to determine the amount of achievable or desirable control and whether or not projects should proceed at all. A project should not proceed if its marginal damages exceed the marginal emission control costs (e.g., at Q_0 in Figure 3), at the levels utilities can afford to install controls (determined by the costs of alternative sources [11]). It is important to note that it is difficult to get agreement on either the location of the equilibrium point or the threshold below which no damages occur. Economists try to determine the former, health professionals and regulatory agencies estimate the latter.

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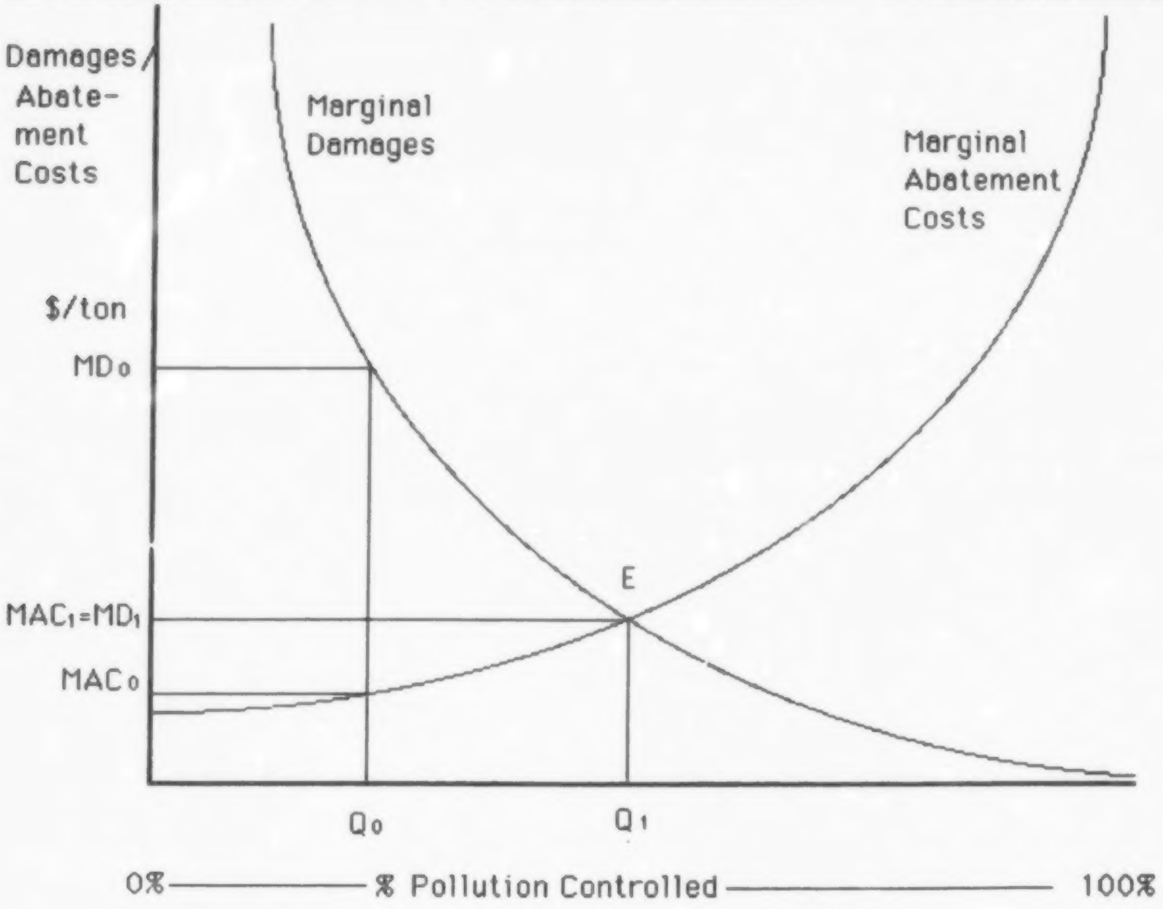
[11] Utilities can afford to install emission control or mitigation up to the point where total costs (including externalities) of a preferred generation option exceed total costs (also including external costs) of the next best method of providing a given energy increment.

Figure 3. Pollution Damages and Control Costs



Valuing Air Emissions

The proper method to value external air quality effects is to estimate the changes caused by the air emissions, consider who is affected, and estimate the value of the change based on who "owns" the resources. The total cost of all air quality effects is the sum for all pollutants of the effects of each individual pollutant on all resource uses.

The primary concern regarding air emissions is their effect on human health. Damage estimation involves all the steps in Figure 1: determining the concentration and dispersion of pollution, after emission controls have been applied; identifying the population affected; estimating probabilities of increased incidence of morbidity or mortality from toxicological studies, if available; valuing the increases in morbidity and mortality, per person, and multiplying the result by the expected increase. The rights to good health are generally[12] presumed to rest with the victim, implying that a compensation standard is most appropriate for valuation. A willingness to pay measure would underestimate health effects.

Data collection methods include:

1. survey of pollution victims (or prospective victims) to determine the willingness to accept compensation for the inconvenience, pain and suffering resulting from a range of increased damages;
2. estimation of increased medical care costs;
3. estimation of productivity losses to society; and
4. expected values of the loss of life.

Secondary measures include lost property values due to increased risks of morbidity and mortality (e.g., how much will the value of a house change if a toxic waste dump is discovered nearby?)

Any mortality value is controversial and uncertain; it is difficult and imprecise to put a value on a human life. If life is claimed to have an infinite value, it becomes cumbersome to undertake any activity, including driving a car, which has a non-zero probability of increasing the risk of death. An infinite value runs counter to the way people actually make choices, where actions increasing the risk of death are taken routinely. Conversely, if no value is included in the estimate, the implication is that people are indifferent about increased risks of death, which is also clearly false. Some measure must be used; measures which account for people's own valuations of their lives have the most merit, which make contingent valuation surveys preferred (Freeman, 1979), although significant information can be derived from jury liability awards. Mortality values currently used range from about $1 million to $5 million per premature death.

Contingent valuation uses surveys to elicit, for example, the compensation people would accept (or their willingness to pay, if appropriate) to experience or avoid different levels of mortality risk over varying periods of time[13]. A probabilistic demand curve for reductions in the risk of death is then derived from survey results, with expected values for each level of exposure to risk. The area under the demand curve (as in Figure 3) represents the total value of reductions in health damages stemming from improved emission control. If controls are in place to Q_1, the damages are the total of the area below the demand curve to the right of Q_1. In the absence of controls, the area below the entire demand curve represents total damages. Where the demand curve intersects the horizontal axis, damages are eliminated entirely.

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[12] Not all economists would agree that compensation measures are required, or with whom the rights reside. see: Coase, 1960; Murdoch & Thayer, 1990; Willig, 1976)

Morbidity is the increased (or decreased) level of illness or disability associated with some environmental cause. Morbidity is measured by the change in the ability of individuals to perform or enjoy a range of activities. One current unit of measure is the activity day. Activity days must be specific to an environmental effect to have validity. For example, smog in Los Angeles reduces the activity days of asthmatic residents for performing different tasks (such as leaving the home) either by increasing their risk of damage or suffering, or by forcing them to limit activities to avoid these risks. The degree of reduced activity experienced is important because an inability to leave the house has a higher cost than, for example, reduced scenic visibility, although both curtail desirable activities. Activity days can be valued through contingent valuation; responses elicited should be specific to the types of damages expected from a particular project (or energy source). Other measures of morbidity include pain and suffering, lost productivity, increased medical care, etc. The analyst using combinations of these approaches must be sure not to double count effects among approaches.

The concept of time is important to valuation. Because life is uncertain, and for other valid reasons, health risks experienced twenty years in the future are valued less than equivalent risks today (Cropper, 1990). Stated another way, people would be willing to accept less for being exposed to an increased probability of death in the distant future than for the same risk today. The method of equating similar risks, costs or benefits over time - discounting - is dependent on selection of a discount rate that accurately reflects people's time preference, not excluding their concern for their progeny's well being. This is a matter of debate among economists (JEEM[14], March,1990). As a practical matter, real (inflation adjusted) discount rates of 3% to 5% are commonly used to evaluate future risks[15].

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[13] Contingent valuation surveys are used to value many other environmental benefits and costs as well.

[14] Journal of Environmental Economics and Management

Some utility planners have suggested using marginal emissions control costs (per unit of pollution emitted) at current regulatory standards as an alternative to damage estimates for valuing emissions (Chernick and Caverhill, 1989; Tellus, 1990). This is also called an implied valuation method. There are two reasons for using control costs: 1. they are easier to derive than damage estimates, and 2. when marginal control costs are estimated at the current regulatory standard, they might be interpreted to represent society's willingness to pay (hence the implied value) for a given level of emission reduction[16]. It should be obvious from the above discussion that damage estimates are inexact, expensive and hard to come by. However, by not actually considering damages, control costs may either over- or underestimate the correct amount of control (point E in Figure 3) by wide margins. Control costs may serve a short term purpose to get external costs included in supply plans, however, they are a poor substitute for damage estimates, and should not be used, if possible (Krupnick, 1991; Freeman,1979).

The external costs of EMF can be evaluated using several techniques in combination. Health effects, given knowledge of the exposure incidence of workers and others in the danger zone near transmission and transformer facilities, can be evaluated as above[17]. Effects on land use (residential, commercial, industrial are strictly market values, and must include lost land uses for the transmission right-of-way, and declining property values as a result of proximity of the transmission line. Visual effects, if relevant, can be determined through surveys, and estimated changes in property values and, effects on wildlife can be determined, depending on whether the wildlife use is survival/cultural or recreational, as described with fisheries, below.

The effects of nuclear power require special consideration. With nuclear facilities, accurate risk assessment is critical, since the damages associated with catastrophic releases of radioactivity are great. Until Three-Mile Island, Chernobyl and numerous subsequent reports of less dramatic releases, the nuclear industry and regulatory agencies maintained that the risk was miniscule. Even without an actual incident, fear of nuclear accidents or routine releases can have adverse consequences on property value and land use that should be considered in siting decisions.

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[15] The higher the discount rate, the lower the future value will be in comparison to today's value.

[16] This argument assumes regulations are rationally derived, based on damages; substantial economic evidence suggests that they are not.

[17] While electric appliances also produce EMF, the use and proximity of these are not within the scope of utility decision making.

Reactors have different design, safety, and emissions control features, so it is probably an overestimating to generalize from an accident like Chernobyl to a new CANDU reactor. Estimates of deaths from Chernobyl, including on-site and latent cancers in the northern hemisphere (determined from dispersion and exposure to various levels of radioactivity) range from 28,000 to 140,000; estimates of lingering illness range from 140,000 to 185,000. At $400, 000 per illness and $4 million per premature death, the total costs of the Chernobyl accident are estimated in the range of $400 billion to $580 billion. The probability of such an accident occurring, based on an U.S. Nuclear Regulatory Commission estimate, is 1/3333 per unit year. Multiplying this probability by this outcome and levelizing for average output of U.S. reactors would add 2.0¢ to 3.1¢/kWh (Pace, 1990). While the likelihood of a Chernobyl-like incident with CANDU reactors may be remote, the possibilities of such outcomes should not be ignored, and some externality value should be incorporated into source decisions.

Additionally, routine releases at most nuclear facilities cause cancers in workers on the order of 1.45 deaths per gigawatt year. Radioactive waste storage, transport and disposal, decommissioning and routine maintenance all have accompanying risks of releases or exposure which should be factored in. The same general approach is used to evaluate these risks as for catastrophic releases or other health effects.

Damages other than health include reduced visibility, fish kills from acidification, corrosion, property soiling and other damages. Effects on fish will be considered under water quality, below. The remainder of these are primarily economic consequences, so valuation is relatively straightforward. Damage costs are related to the use remaining in the damaged good, or the cost of fixing the damage. If corrosion shortens the life of machinery or other equipment, the damage is the discounted difference between replacement dates and costs. For example, if a new car requires repainting ($1,000) in three years, instead of six, the present value of the pollution cost (5% discount rate) is:

$$\$1{,}000/(1.05)^3 - \$1{,}000/(1.05)^6 = \$117.62$$

Alternatives to present valuing include using various depreciation methods such as straight line or double declining digit. Any of these are acceptable as long as the method is explicit and the focus is on differences with and without pollution. Some goods, such as historic buildings or other cultural artifacts may not be replaceable, and may require costly repairs or increased maintenance or cleaning, if possible, to counteract pollution. In these cases, the costs of repairs or maintenance measures are the externalities associated with pollution. The increased costs should be allocated over time and discounted back to present value dollars to provide the most accurate figure.

Where cultural or unique resources are lost, and can not be protected through increased expenditures, an alternative methodology is used. Some unique resources have value to those who have never used or visited them, but might want to some day, or may simply want to have the resource preserved for posterity. The former is called option value (where the individual is willing to pay something to preserve the option of using it someday, the latter is called bequest value, where someone wants to leave the resource for future generations to use. Both of these values tend to be small, but non-trivial, compared to actual use values. Both are derived through contingent valuation surveys (Fisher, 1981).

Other effects of air pollution include productivity changes in agriculture, forestry, tourism, visibility and property values. Air pollution can reduce or eliminate the potential of land for raising livestock or growing crops or trees. Effects can be either short or long term. Short term effects may be diminished growth as the result of gasses emitted that interfere with normal biological processes. Long term effects include contamination of the land to the extent that neither crops nor livestock can be raised on it (e.g. where toxic metals concentrations are too high). For valuation, where production is reduced, the net value of expected reduction per year is summed and discounted back to the present. Depending on the pollutant, the land may recuperate if pollution is curtailed, or it may not if the pollutant is persistent (such as long-lived radioactivity). If production is completely curtailed, the loss is the discounted sum, for all relevant years, of the difference in net value between the productive activity lost and a remaining use of the land. For example, a piece of property may not be suitable for producing food, due to persistent toxins in the soil, but may be adequate for forestry. Where a change in land use as a result of air pollution is permanent the formula for calculating the cost is:

Total cost = Annual net loss/interest rate[18]

The same formulas and procedures are used to calculate tourism losses and changes in property values. The effects of pollution on property values are determined through hedonic regression techniques (below).

Water Quality and Quantity

A number of electricity generation options affect water quality and quantity, with resultant impacts on aquatic resource use. Among the effects are surface water acidification, cooling water disposal, flooding, elevation of mercury levels in reservoirs and fish, changes in timing and volume of stream flow, limitations on alternative uses of water (e.g. navigation, recreation or flood control), effects on fisheries, barriers to fish passage, mechanical hazards for fish (turbines and entrainment). With the exception of flooding and mercury poisoning, most of these are economic and social effects.

Fisheries appear to be the aquatic resource most affected by energy projects. Fish kills occur as a result of hydroelectric development and cooling water disposal by thermal power plants. For economic evaluation purposes, there are three types of fisheries, survival/cultural, commercial and recreational; each must be evaluated differently.

1. Survival/Cultural Fishery

Where aboriginal culture or routine survival is dependent on a fishery, it is a virtually irreplaceable resource, and one to which the rights are clear, compared to other, more general access fisheries. Treaties in the United States and Canada, and court decisions defining implementation of those treaties have generally tended to award the ownership of treaty fisheries or cultural/survival fisheries to aboriginals (or Native Americans). For purposes of analysis, this report will follow the logic of Judge Boldt in U.S. v. Washington (1974), and in the British Columbia Sparrow decision of 1990, both of which assigned significant fisheries rights to aboriginal groups. The implication of this, from the health discussion above, is that any evaluation of damages to the survival/cultural fishery resource must use a compensation measure. At minimum, the value of the fishery must be established at replacement costs, a considerable sum if the damage to the resource is great and fresh fish must be flown in to remote locations to replace the losses.

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[18] e.g., an annual loss of $1 million and an interest rate of 5% ($1,000,000/.05) gives total damages of $20 million

In a simplified version, an evaluation of electric generation impacts on survival/cultural fisheries would involve estimating project related changes over time on the most important component of the fishery as defined by the aboriginal users. [The most important component of a commercial fishery is the amount of fish caught, per fishing effort (losses are initially measured by weight), while for a sport fishery, it is the activity of catching the fish, rather than the pounds caught, which is most important (losses are measured by fishing-day, which is correlated to amount of fish)]. In a survival/cultural fishery, a significant measure may have elements of both. While a survival fishery could be replaced at some cost, cultural aspects of a fishery - traditions, ceremony, traditional livelihoods and community structure - may be considered irreplaceable by those affected.

The fishermen and their communities must establish the value of the fishery. For some, there may be acceptable replacement values; for others that value may be infinite. Insofar as individual values differ, it is possible to construct a demand curve for the fishery, the sum of the area under the demand curve representing the total value of the fishery to its users.

To the extent that a value per kilogram or fishing day can be established, through surveys or interviews, losses can be estimated over time and discounted to present value. Figure 4 shows a similar analysis of projected fish catch losses over time as a result of timber harvesting. The patterns of response of the fishery to an energy project would differ, but the analytical method would be similar. The key points of the analysis represented by this graph are 1. it considers only the net effect of an action - the difference (the shaded area) between fisheries response with and without timber harvesting - the without condition is represented by the horizontal line (Pre-Logging Catch Level); 2. it incorporates changes over a significant period of time (140 years); 3. it relates a biological measure - fish mortality (not shown in graph) to human use - catch (shown in graph). Assuming a downward sloping demand curve[19], the larger losses in fish catch in Figure 4 would have an greater marginal value per kg. (or lb.) (because fewer fish would remain) although these losses occur further out in time and would therefore be discounted more heavily.

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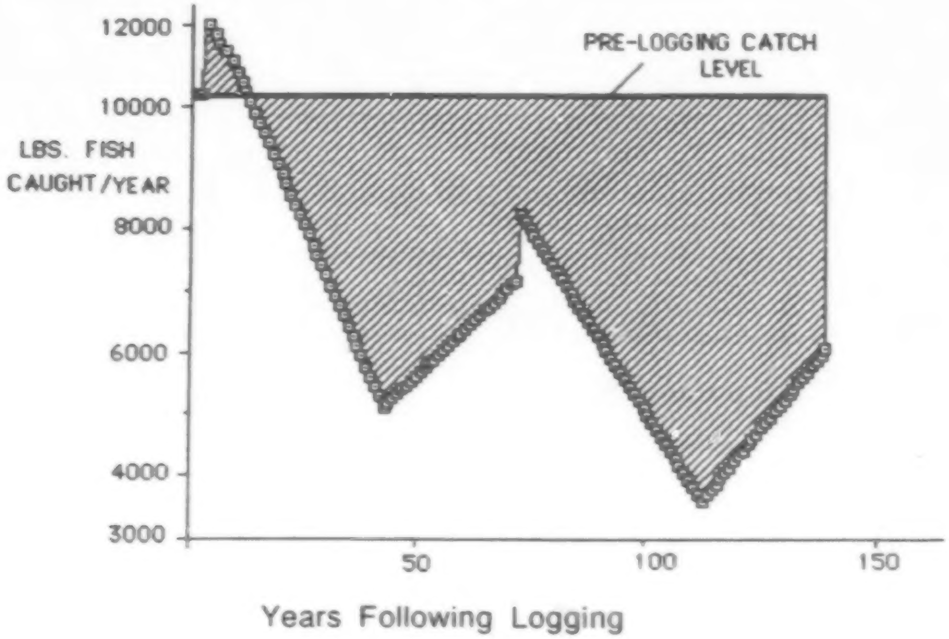
[19] Supply scarcity caused by fish kills from whatever source, would increase competition for the remaining resource, which would drive up its price.

Figure 4. Effect of Logging on Coho Salmon[20]



2. Commercial Fishery

The damage to the commercial component of a fishery is estimated as in Figure 4, but values are derived from current market prices. Property rights are not particularly relevant to valuation where a market exists, because the goods will be traded at the market price[21]. It is important that the values used are net values, without costs attributable to fishing effort. Otherwise, avoided fishing costs are erroneously classified as lost benefits. Where future demand for the fishery is known, real price growth or decline should be included in the externality value. For example, if demand for fish has been growing faster than demand for other products, a real growth in fish prices ($/kg) could be expected. This growth rate is included in the calculations for each future year, prior to discounting. (As with other forecasts, predictions of real price growth are sometimes wrong).

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[20] source: Clark, 1988.

[21] It is important to understand who has the property rights to show who wins and loses from a project and by how much, if compensation is not paid.

3. Sportfishing Values

Effects of utility projects on sportfisheries are analyzed in the same manner as above, but, again, valuation is different. Because the focus of sportfishing is the activity, the value is related to how much people are willing to pay for the activity. Willingness to pay for sportfishing is appropriate since no one "owns" a sportfishery and it is a discretionary activity by definition. It is also very valuable, in some cases with sportfishing values per pound being multiples of commercial values.

Sportfishing willingness to pay is measured in recreational activity day. The value of an activity day is related to the quality of the experience, which is generally related to the number of fish caught. The total pounds of fish caught is less important than the number caught and the size of the fish. Among fishermen, bigger is better. Evidence of this is the growing popularity of catch and release practices which increase both the size and number of fish that can be caught, creating more potential activity days and increasing the total value of the sportfishery. It should be clear that there is an important relationship between the availability of fish to be caught and the value of the sportfishery. Actions which reduce fish numbers, size or survival rate reduces the sportfishery value.

Economists have measured the value of a recreational activity day in a number of ways. A longstanding measure is travel-cost, one version of which determines the various distances people travel to get to a certain destination (the one affected by the project), imputes a cost for traveling that distance, totals the costs for all visitors from all distances and the cost represents the current equilibrium price intersection of the demand curve. Other points on the demand curve are estimated by assuming visitation will increase and decrease equivalent with changes in travel costs, all other things remaining static. Again changes in availability of the fishery resource will result in a change in the area under the demand curve available to recreational fishermen. Added to this value is the discounted net value of profits lost to associated industries - guides, tackle and bait shops, lodging, etc. The sum of these elements represents the total loss in sportfishing values.

An alternative measure of value is called "hedonic valuation". Hedonic methods measure the use, for example, of a number of recreational sites or resources, and estimate a value for each site based on the quality of the good or site. Value of a site is equated with quality. Multiple regression is used to measure the contribution of the site's characteristics, such as size and number of fish caught, scenery, or distance, to its total desirability. The proportional contribution of each characteristic to total value gives the value, or shadow price, of the characteristic, The total change in the level of each characteristic caused by a project is multiplied by the shadow price to give total value.

The information for hedonic recreation valuation is usually gathered through surveys. Other hedonic studies do not use surveys, but rely on published data. One example is the relationship of pollution to housing value. Economists have evaluated houses for a number of characteristics and have been able to estimate changes in housing price based on such attributes as scenery, noise and air pollution levels. A hybrid method which holds promise for recreation valuation is the hedonic travel cost method (Brown and Bishop, 1985) which uses the costs of travelling to a site as an estimate of site value and compares this with the characteristics of the site to derive values for the characteristics.

Alternative Measures

The air emissions control costs/implied valuation method described above has a corollary in aquatic resources. It is possible to suggest that the foregone benefits of dam planning, operation or mitigation measures imply a value for the resources benefitted. If, for example, power generation is foregone to provide a scenic river in a national or provincial park, it might be assumed that society values the park is at least as much as the net value of that power. The problem with this assumption is that while it is true, it is neither accurate enough for analytical purposes, nor is it transferable to other sites. If the site is unique (like the Grand Canyon or Niagara Falls, both of which involve constraints on hydraulic generation) the value of the amenity resource may be many times the power foregone, while at another site, the power value may exceed the value of relatively abundant resources. Because the avoided benefits/control costs/implied valuation approach does not take into account relative scarcity or abundance of a resource, comparison among sites is tenuous and depends on more qualitative comparisons of values (hedonic and contingent valuation methods are intended to quantify these qualitative aspects). However, the existence of power production constraints which benefit amenity resources indicates an acknowledgement on the part of utilities that externalities have a social value, and that they should be willing to develop more exact assessment procedures.

Effects of Dams

Dams and inundation cause several adverse impacts, including changes the species composition and quantity of fish, elevation of mercury levels in the fish, elimination of some uses (such as river rafting), increased potential of dam failure, and effects on surrounding game and non-game habitat and property values. Fish have been discussed, with one addition: increased mercury levels, insofar as they make the fish inedible by reasonable standards, should be treated as a total fish loss, i.e., as if all fish were killed. If the fish are edible but lead to increased morbidity and mortality, the method for calculating those effects should be followed.

Dam failure is similar to catastrophic releases of radiation, a low-probability event, with a potentially high cost. Engineers develop probability estimates of damage and loss of life given information on the location of populations and property downstream. These figures are used to calculate the externality value.

Loss of riverine recreational uses is calculated in the same way as sportfishing, with the quality of the river a product of its characteristics and uniqueness. Property values can be affected partially, if fluctuation leaves mud in the yard a substantial portion of the year, or when waterfront is created where none existed previously, or totally, as when land is inundated. Regression methods can evaluate the difference in property values with and without mud or lake frontage; in the case of total loss, a simple market value is used.

Changes in wildlife habitat values take a variety of forms: inundation eliminates some wildlife habitat completely; concentration of mercury through the food change may reduce the usefulness of some wildlife to man; and lakes create an edge effect beneficial to some wildlife, though perhaps not all. Valuation depends on use. Survival/cultural hunting, commercial trapping and sport hunting are each valued in the same manner as their fishery counterparts. Non-game habitat is valued by hedonic methods, where it contributes to some other value such as property, or by contingent valuation for the option and bequest values.

The mere siting of a plant, even without external physical effects can make certain land uses infeasible or undesirable, for example, a power plant sited near a national park may make the park a less attractive destination.

Other Externalities

There are other externalities which are not strictly environmental, but which clearly affect people's quality of life. Among these are employment creation, congestion and alteration of traditional patterns of life and behavior. Employment, a positive (beneficial) externality can be estimated through input-output analysis, which traces investments in one economic activity throughout the whole economy. While direct valuation of employment effects has been limited to date, net present value estimates could be derived. Changes in communities and cultures are harder to estimate. Many social changes are unforeseen. Some people like the changes, some do not. The lack of foresight requires careful thought before initiating actions which can alter cultures irreversibly.

Incorporation of External Values into Energy Planning

A least-cost, or integrated management process, selects the combination of electricity supply and demand sources that have the least social cost. Total externality costs are estimated, based on emissions or effects from each source (multiplied by unit costs), and control measures selected. The external costs are combined with the usual fixed and variable cost calculations[22] to provide a total social cost measure. This monetization procedure allows a complete accounting of all costs to society on an equal basis.

Conclusions

Electricity generating activities often result in external costs to society, many of which are the result of damage to the environment. Different damages, or changes in resource use levels, require different valuation methods. Most often, specific studies are unaffordable and the best that can be done is to extrapolate from similar studies elsewhere and correct for the difference in significant variables or parameters such as population, site characteristics, species composition and aboriginal rights. Other studies provide a model which can adjusted, with some loss of accuracy, to reflect the conditions of interest. Techniques other than those identified in this report exist, but the methods described here cover most of the currently accepted valuation methods.

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[22] i.e. direct costs currently internalized by the energy provider

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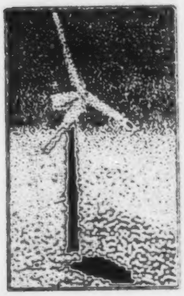

EFFECTS OF THIS COSTING METHODOLOGY ON WIND ENERGY

The Social Costs of Electricity Generation

Calculation Methodology: Evaluation of Social Costs

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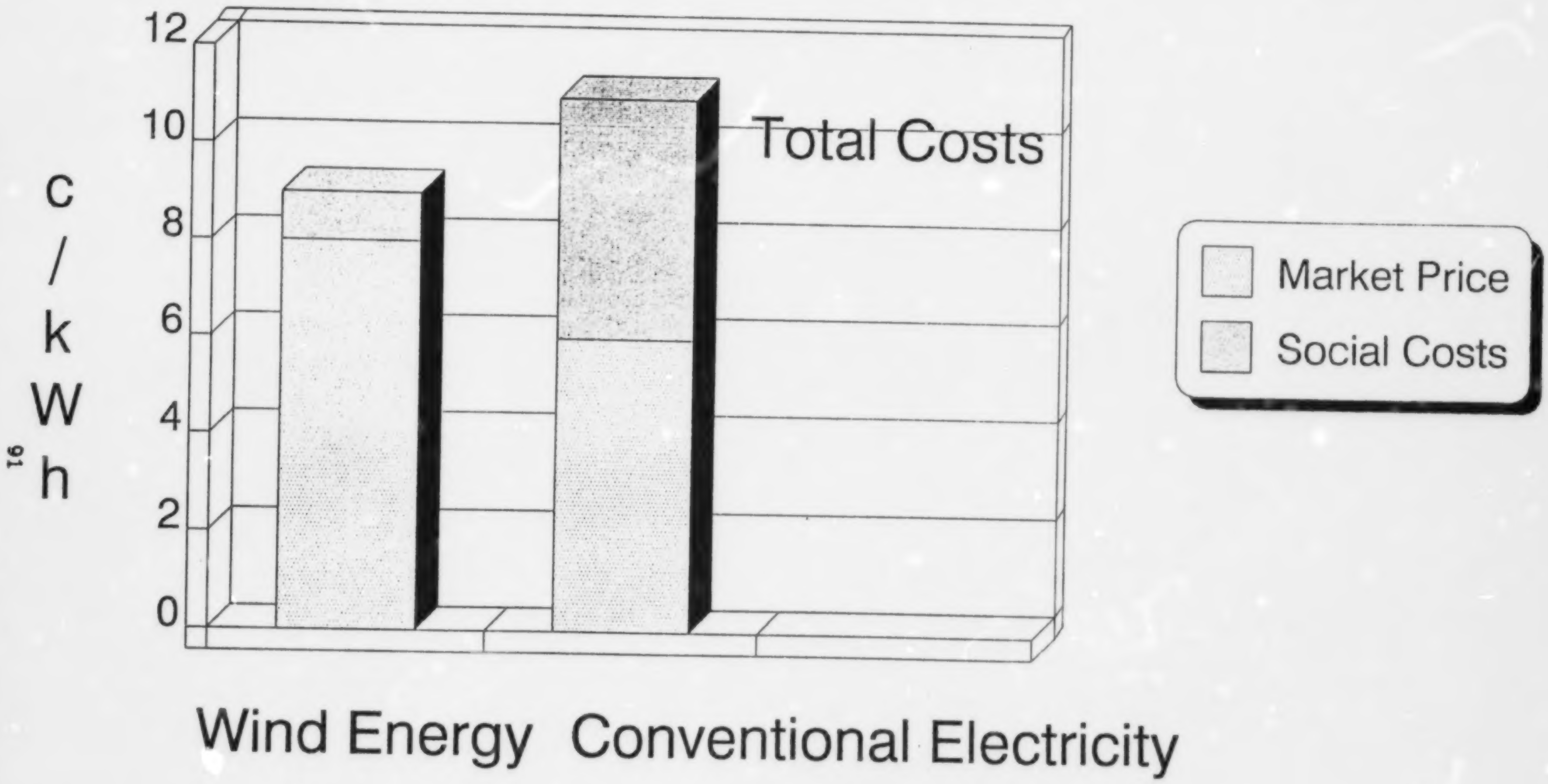
O. Hohmeyer, FhG/ISI, 10/1991

What are social costs?

Social costs are those costs of production or consumption passed on to third parties not involved as producers or consumers of a product and, therefore, are not included in the market prices.

Examples of social costs of energy consumption are:

- climatic changes due to the incineration of fossil fuels and the resulting effects like large scale droughts or flooding of river deltas
- serious forest damages due to the emission of air pollutants from combustion processes
- release of vast quantities of radioactive isotopes from nuclear accidents like the Chernobyl catastrophe.



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WHAT ARE SOCIAL COSTS ?

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O. Hohmeyer

- Market prices play a central role in market economies
- Scarce resources are allocated through market mechanisms based on market prices
- Macreconomic optimum can be achieved by individual utility maximisation ('Invisible Hand'), if market prices reflect all costs
- If substantial cost elements are not reflected in market prices, markets cannot fullfill their fundamental task
- Thus, governments have to make markets function

Social Versus External Costs

Social costs:
private + social costs
= full costs to society

- including macroeconomic effects
- including aspects of sustainability

External costs:
internal + external =
social costs

- only narrow definition of microeconomic effects included
- other costs to society excluded

O. Hohmeyer, FhG/ISI, 10/1991

Categories of Social Costs

- ►Environmental and health costs
  - direct and indirect costs
  - routine operation and accidents
- ►Long run resource costs
  - intertemporal equity
  - international equity
  - sustainability
- ►Macroeconomic net effects
  - positve net benefits (employment)
  - serious indirect disruptions (accidents, climate change)
- ►Subsidies without real use for society
- ►Costs of social disruptions (Chern.)
- ►Costs of political disruptions (Cher.)

O. Hohmeyer, FhG/ISI, 10/1991

Possible Ways for Monetization

- ►Direct monetization of damages
  - market prices for damged goods
  - repair costs for damages done
- ►Indirect monetization of damages
  - contingent valuation
  - control costs to avoid damage
  - marketable permits
- ►Implicit monetization
  - scoring plus price attributes
  - restrictions on emissions leading to shadow prices

O. Hohmeyer, FhG/ISI, 10/1991

Pros and Cons of Explicit Monetization

- **Cons:**
  - ► Less cynical
  - ► Seems to be ethically sounder (not to value human lives in $)
- **Pros:**
  - ► Direct comparison with other costs possible
  - ► Integration into market mechanisms possible
  - ► Integration into planning easier
  - ► Explicit valuation instead of implicit valuation

O. Hohmeyer, FhG/ISI, 10/1991

Environmental Costs: Quantification Problems

Lack of knowledge:

- ► Cause-effect chains often hardly known
- ► Accumulation and threshold effects the rule not the exemption
- ► Synergetic causalities of damages general feature of the problem
- ► Many emission sources of one pollutant
- ► Quantification of impacts sometimes difficult (effects of climate change)
- ► Future effects only vaguely known
- ► Little knowledge about actual physical, chemical and biological damages

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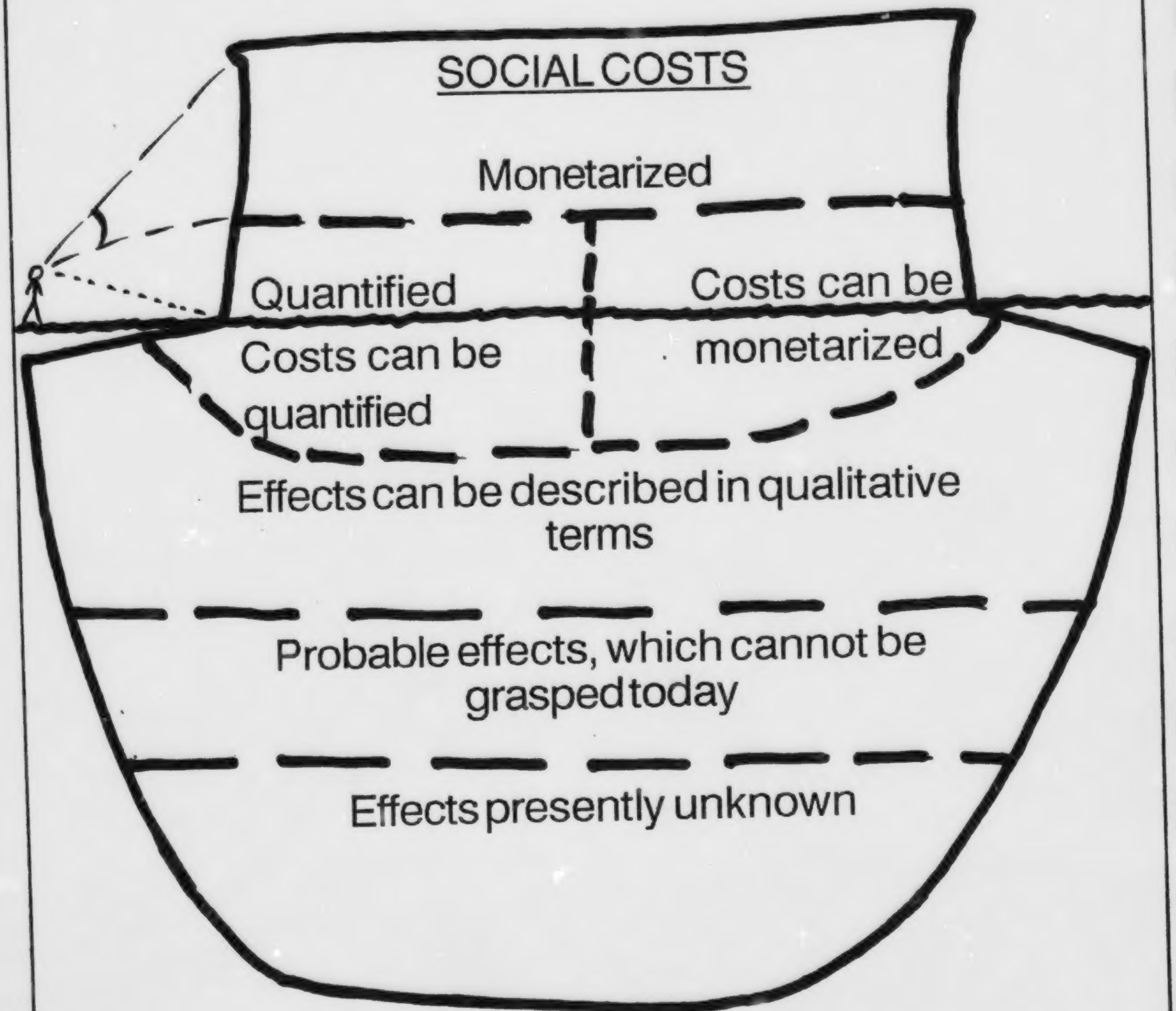
The total social costs of electricity consumption can be compared to an iceberg:



SOCIAL COSTS

Monetarized

Quantified

Costs can be monetarized

Costs can be quantified

Effects can be described in qualitative terms

Probable effects, which cannot be grasped today

Effects presently unknown

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Present knowledge on the social costs of electricity consumption

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- Conventional electricity generation seems to have considerably higher social costs as renewables

Three central questions have to be addressed:

1. How large is the difference between the social costs of conventional electricity generation and renewables?

2. Is this differnce large enough to effect the competitive position of renewables?

3. How does it effect the market introduction of renewables?

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Social Costs of Energy

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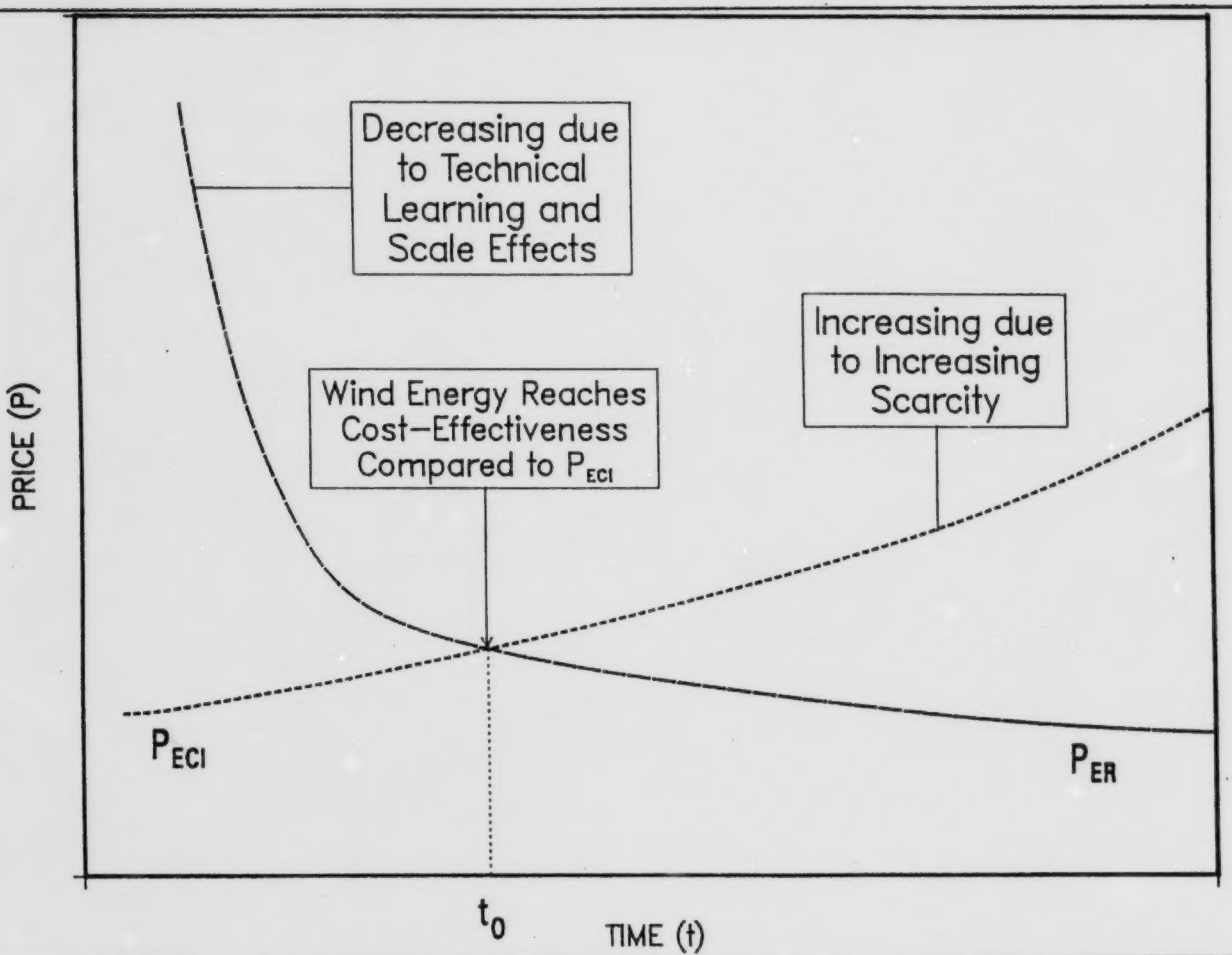

I. Cost Develepment of Electricity Generation Over Time
P_{ER} : Wind Energy
P_{ECI} : Conventional Electricity, Only Internal Costs

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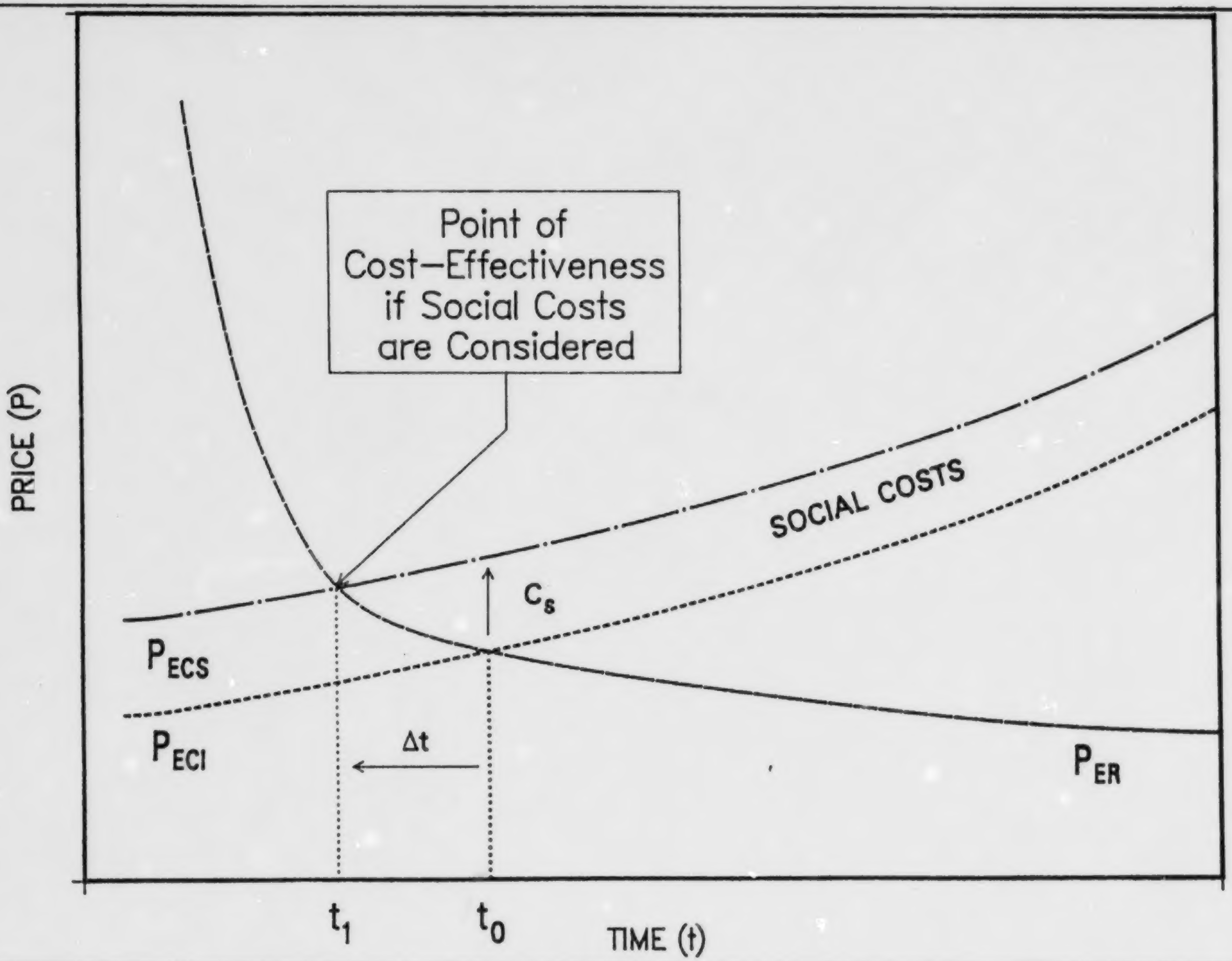
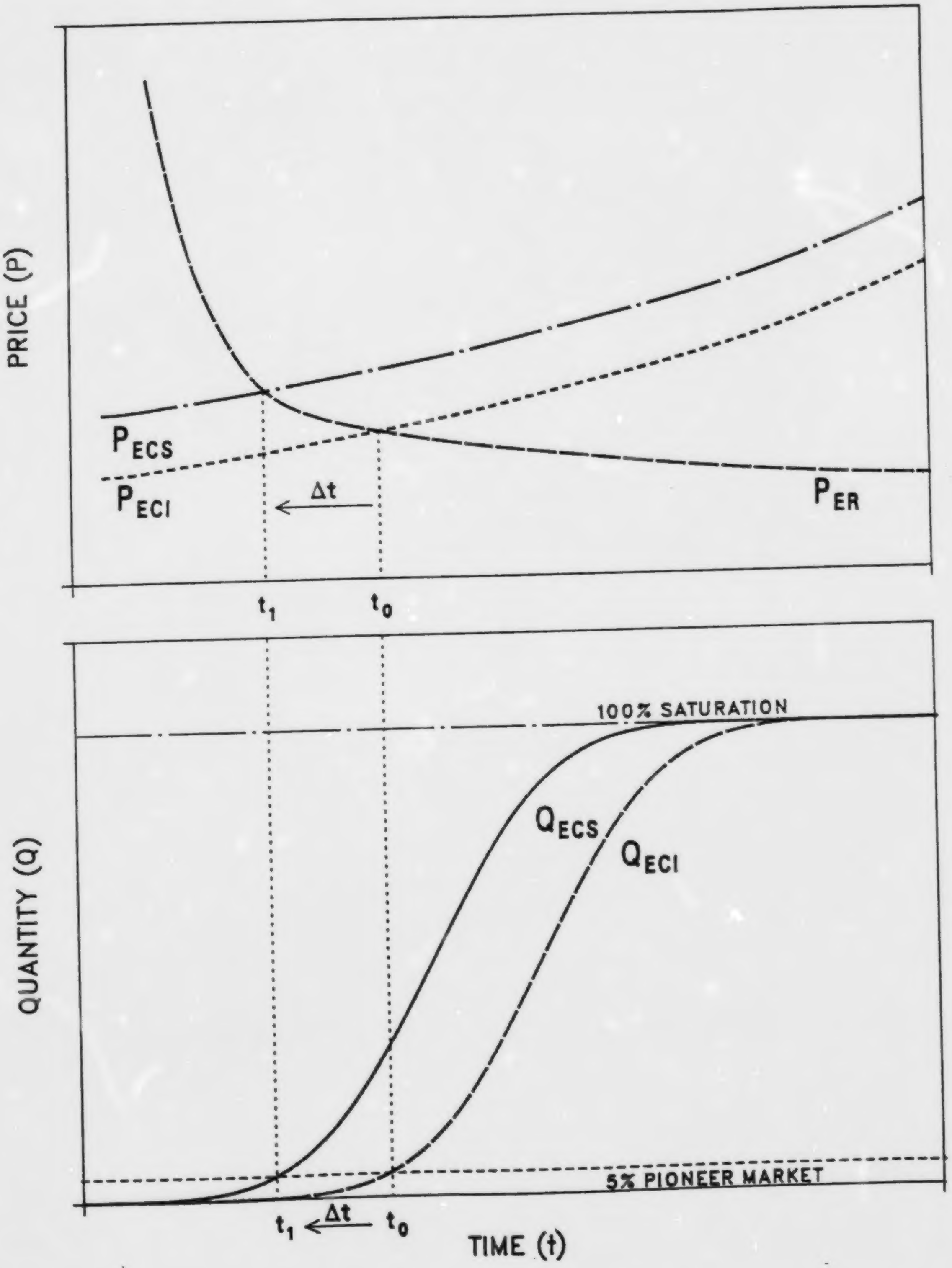
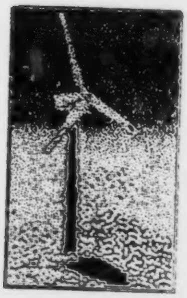


II. Cost Develepment of Electricity Generation Over Time
P_{ER} : Wind Energy
P_{ECS} : Conventional Electricity Including Social Costs

O. Hohmeyer



III. Market Diffusion of Wind Energy due to the Handling of Social Costs
Q_{ECI}: Market Diffusion Curve Without Considering Social Costs
Q_{ECS}: Market Diffusion Curve Taking into Account Social Costs



IMPLEMENTATION SCENARIOS

SOCIO-ECONOMIC OVERVIEW OF WIND ENERGY CONVERSION SYSTEMS

Collaborative Paper

by

Corporate Relations Planning and Research Department
Ontario Hydro
and
Hardy Stevenson and Associates

for the

CANWEA Wind Energy Seminar

on

THE SOCIAL COSTS OF ELECTRICITY GENERATION

Attitudes of the Utilities: Implementation Panel

November 4, 1991
Montreal, Quebec

Presented By: D. R. Hardy, M.C.I.P.
Hardy Stevenson and Associates
Toronto, Ontario, Canada
(416) 693-6115

PREAMBLE

I will begin by clarifying the approach I am taking, compared to the approaches taken by my fellow panellists.

First, Ontario Hydro has collaborated and supported Hardy Stevenson and Associates (HSA) in producing this paper. However, the points I raise are the perspective of HSA. I say this, not to assign credit, but to ensure you understand that the views presented are our *observations* of Ontario Hydro policy and research. Not official Ontario Hydro policy.

Second, this paper will be a social scientists' perspective on the socio-economic impacts of wind energy conversion systems, (WECS), as opposed to an economists view of the social costs. Thus, I will be making observations about social costs, not from the perspective of the costs to the consumers in the Province of Ontario. But, social costs in terms of who wins, who looses, who benefits, who pays, and who experiences impacts through the implementation of Wind Energy Conversion Systems.

Third, until recently, there has been minimal research completed by Ontario Hydro on the socio-economic impacts of alternative energy systems of any type. Hydro research has, overall, concentrated on those technologies that offered the greatest potential for future applications in the foreseeable future.[1] The Ontario Hydro study[2] to which I will refer, (Alternative Energy Review) is an overview study to meet the requirements of the Ontario Ministry of Environment's, Environmental Assessment Board Hearing of Ontario Hydro's Demand/Supply Plan[3]. The supporting data and conclusions of this paper can therefore be considered preliminary.[4]

Inspite of the data limitations, our research may be useful. And, even though some socio-economic impacts are anticipated, Wind Energy Conversion Systems are seen to have fewer socio-economic impacts compared to other conventional and alternative energy systems.

INTRODUCTION

I'll explain why WECS are favourable, on socio-economic grounds, by sharing our observations about several aspects of Wind Energy Conversion Systems as they apply in the Province of Ontario.

To place the following remarks in context, I'll discuss the climate within which Ontario Hydro is currently planning - essentially, the climate within which WECS would be seeking approval and implementation.

This is an important part of the discussion of implementation (the topic of this panel) for two reasons. First, "alternative technologies which may hold promise for commercial use in other jurisdictions may not be well suited to Ontario because of uncontrollable factors including geography and climactic differences and fuel availability."[5] And, second, even alternative technologies that appear socially benign, such as composting, are being contested by local citizens and sectoral interest groups. Being a sustainable technology does not guarantee social acceptance and approval.

I will move on from there to review of characteristics of WECS where we anticipate there may be socio-economic impacts.

I will conclude my remarks by presenting an overall assessment of the potential social barriers to approval of WECS. And, an assessment of the potential strengths of WECS within Ontario's energy system.

ONTARIO'S ELECTRICAL SYSTEM AND THE CLIMATE FOR THE IMPLEMENTATION OF WECS

As a number of you are from outside of Canada, I will start with a few background remarks about the electricity system within which WECS would be implemented in Ontario.

- The principle organization for the delivery of electricity in Ontario is Ontario Hydro. Ontario Hydro is a publically-owned corporation supplying electricity through an integrated system of generating facilities, transmission facilities and interconnections with neighbouring facilities to deliver electricity to its customers.
- as of the end of 1993, the electricity supply mix in Ontario will be 43% nuclear (20 nuclear units at five stations on 3 sites), 37% fossil (28 units at 6 generating station sites) and 20% hydraulic (265 generating units at 68 stations), for a total system capacity of 32.5 Gigawatts.
- Ontario Hydro's wind energy conversion facilities, now consist of an experimental 3.5 Kw generator operating at Science North in Sudbury. Ontario Hydro also operates a hybrid wind/ diesel facility at Fort Severn, the furthest north community in Ontario.
- overall, Ontario's electrical system is aging. And, like other systems in North America the demand for electricity in Ontario is continuing to grow over the long term.

- to address this, Ontario Hydro is reviewing its options for electricity supply and demand for the next twenty-five years. They are looking at a wide range of options including managing demand, supporting non-utility generation, purchases, rehabilitating existing facilities, and new supply.

- the 'strategy' Ontario has chosen, gives a high priority to maintaining, upgrading and refurbishing existing generation and transmission facilities. It also gives high priority to energy supply that is low cost and environmentally acceptable. Hydro has moved ahead on options common to all of the Plans such as demand management, rehabilitation, small hydraulic and purchases, as these are common aspects of the Plan.

- Ontario Hydro anticipates that wind power would likely be applied in niche applications involving off-grid hybrid systems (eg. wind/diesel), where the cost of the displaced generation is high. On-grid applications of wind power would likely be in the form of dispersed non-utility generation (ie., single wind turbines or wind farms).

- the potential contribution of wind power to the electricity supply mix for Ontario could be as little as **1 MW** by the year **2000** to as high as **40 MW** by the year **2014** depending on costs and technological developments.

As presented in the Alternative Energy Review, WECS considered by Ontario Hydro fall into two general categories: systems producing mechanical power and systems producing electricity. Systems producing electricity are further divided into vertical or horizontal designs. Two options considered by Ontario Hydro for further analysis in the Alternative Energy Review are a:

- 10 kW Single Wind Turbine (representing electrical energy demand of a typical rural residential owner) See: Fig. 2-9-1

- wind farm array of 20 X 350 kW turbines (350 kW represents the optimal size evolving in the industry) See: Fig. 2-9-2

Two scenarios reviewed: the potential contribution by the year 2005 and the potential contribution by the year 2014.

SOCIAL CLIMATE: PUBLIC EXPECTATIONS FOR ANY NEW SUPPLY OPTIONS

I'll now move on to my second point. What is the social climate for the acceptance of Wind Energy Conversion Systems? On the basis of what social criteria will alternative supply options be assessed?

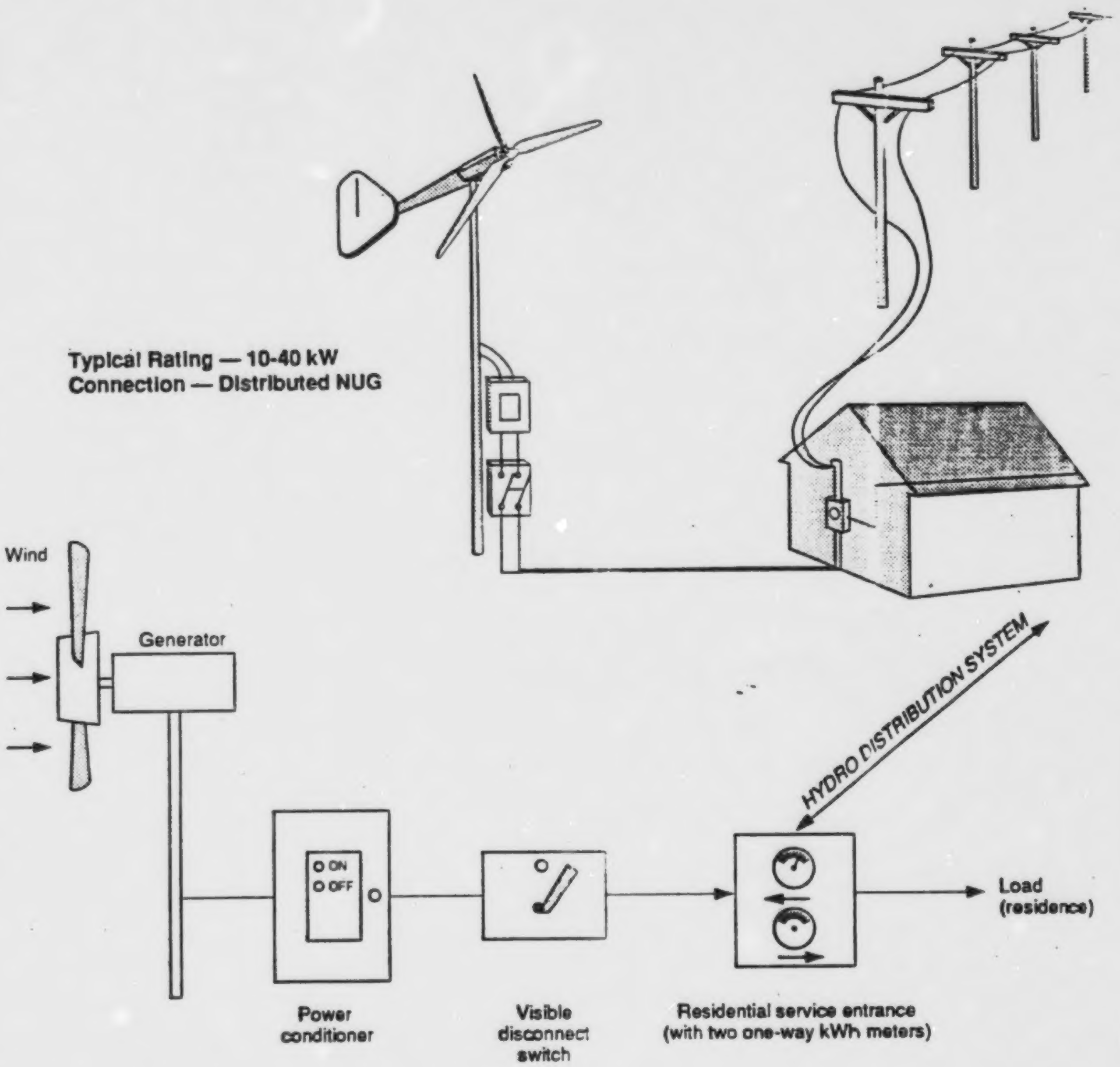

Typical Rating — 10-40 kW
Connection — Distributed NUG
Wind
Generator
ON
OFF
HYDRO DISTRIBUTION SYSTEM
Load
(residence)
Power
conditioner
Visible
disconnect
switch
Residential service entrance
(with two one-way kWh meters)

FIGURE 2-9-1. Small Utility Interactive Wind Turbine. Typically 10 to 40 kW.

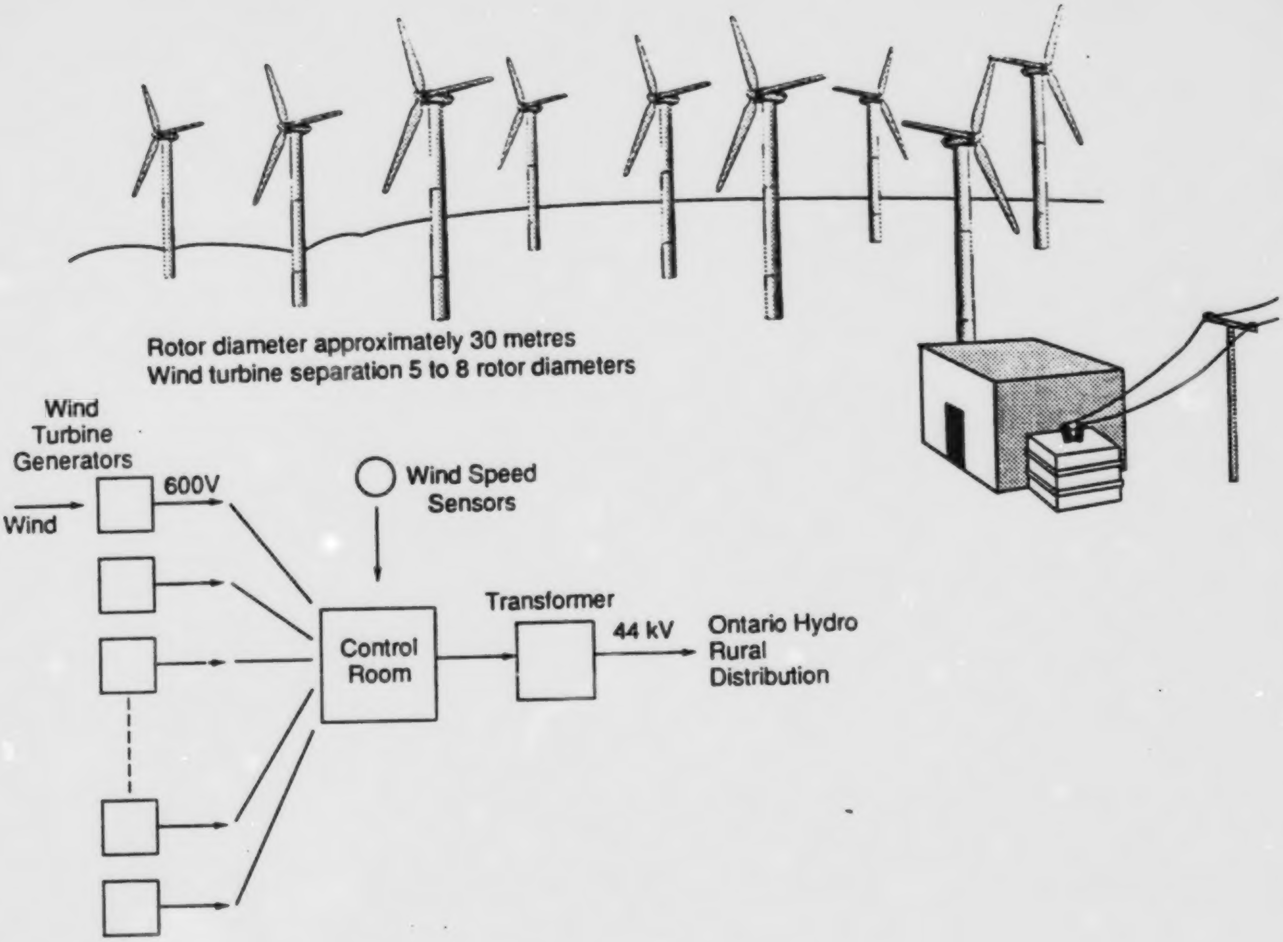

Rotor diameter approximately 30 metres
Wind turbine separation 5 to 8 rotor diameters
Wind Turbine Generators
Wind
600V
Wind Speed Sensors
Control Room
Transformer
44 kV
Ontario Hydro Rural Distribution

FIGURE 2-9-2. Schematic of a Wind Farm Connected to a Rural Distribution System.

Through public consultation research[6] conducted to identify tradeoffs required within the D/SP, Ontario Hydro identified a number of 'overall' expectations that the residents of Ontario have about any electricity options within the energy system.

In addition to low-cost electricity service and the need to meet environmental considerations, the public has said they want Ontario Hydro to pursue options that:

- avoid and minimize social effects
- meet safety requirements
- are flexible in terms of being able to meet changing load conditions
- favour fuels that are renewable and fuels that are in plentiful supply
- are technically sound, in terms of an option's maturity and the extent of Hydro's experience with it
- that are reliable in terms of their availability for service and how the option performs.

Closer to the conference theme of 'social costs', Ontario Hydro has identified socio-economic criteria to be applied in the assessment of individual supply options and the assessment of combinations of supply options, known as Cases[7]. It is these socio-economic criteria that were applied in our part of the study assessing WECS, and they included socio-economic criteria such as:

- *regional employment* - this refers to the potential of WECS to influence regional labour supply and skills. Here, we looked at employment opportunities potentially afforded by the construction of a Wind Energy System.

- *regional economic development* - opportunities that Wind Energy Conversion Systems would offer to develop existing regional businesses and services and the potential for new businesses and services to develop as a result of this system.

- *local community impacts* - this criterion focuses on how the size and service capacity of communities would be affected by project activities and the potential population inflow due to the construction and operation of WECS. This is important, because, for the size of workforce required to implement some options, many communities would require expansion of community or municipal facilities and services such as roads, and water and waste treatment facilities.

The socio-economic criteria applied also referred to general societal considerations, such as:

- *social acceptance* - this is the extent to which new supply options integrated changing social values. These values relate to social/environmental performance and maximum achievement of publically preferred options. The need to consider whether the option contributed to 'sustainable development' was an important factor.

- *special/sensitive groups* - certain population groups may be more affected by change brought on by the construction or operation of WECS, than the rest of the population because of their cultural heritage, size, socio-economic status, or special interests.

- *lifestyle impacts* - this criterion focus's on the impact of an option on the character of the community, the stability of the population and lifestyle. Some social groups are much more resilient to change than others.

- *distribution of risks and benefits* - this is essential an equity criteria that holds that those who bear the risks, should share equitably in the benefits.

The application of these socio-economic criteria, then, was the base from which we have assessed barriers and strengths of the potential implementation of WECS.

Given this, the third point I wish to raise is how wind energy conversion systems have fared when assessed against these evaluation criteria. I'll begin by looking at characteristics of Wind Energy Conversion Systems we anticipate would have socio-economic impacts.

CHARACTERISTICS OF WECS THAT WILL HAVE SOCIO-ECONOMIC IMPACTS

Ontario Hydro, assisted by Monenco Engineering and Hardy Stevenson and Associates, conducted a technical and environmental assessment of alternative energy options including an assessment of: solar energy, wind, fuel cells, biomass, peat and municipal solid waste.

The study of the socio-economic effects began with a description of the technologies, in terms of world operating experience, and the identification of the characteristics of options that were expected to have natural and social environmental effects. From a socio-economic impact perspective, the characteristics of WECS we saw to be important included:

- manufacturing of WECS components
- site location, size and layout of a wind farm
- the length and duration of its construction
- workforce size and residential location of the workforce
- the skills mix required to construct the WECS facility
- potential for emissions and effects on the natural environment
- any hazardous aspects of the undertaking
- safety and security requirements.

We also considered impact avoidance, management and mitigation measures that might be applied to reduce socio-economic effects. And, we looked at what we felt would be local community perceptions of a Wind Energy Conversion System.

INITIAL OBSERVATIONS OF POTENTIAL EFFECTS

Potential socio-economic effects are those changes expected to occur through the construction and operation of a WECS before mitigation measures have been applied, and before net effects have been evaluated. They include effects resulting from site selection, manufacturing, construction, operations and decommissioning.

SITE SELECTION

Potential Effects

Energy output from a wind turbine is very site dependent, therefore, indepth investigation of potential wind sites is required for optimum siting. "Wind speeds ...are influenced by local topography and ground cover as well as height above ground level..."[8] We assumed that, WECS would be located in areas of sustained wind. As indicated on Figure 2-2-2[9], Ontario's windiest sites are located along the Hudson's Bay coastline and along the westward facing shores of the Great Lakes. Good locations in Southern Ontario would be Peele Island, the Bruce area of Lake Huron and around Sudbury.

As referred to in the Alternative Energy Review, WECS units are modular. Discrete units can be added together to create 'wind farms'. They may be arranged in a linear formation along a ridge, or spaced in a cluster with separations of about eight blade diameters to avoid interference. Both configurations will absorb a significant amount of land with land-use restrictions within a .5 hectare radius of the turbines. It is estimated that a wind farm could involve a line of turbines up to 4 kilometres in length depending on prevailing wind conditions.

In addition, wind farms utilize large tracts of land, although much of the land is available for other uses. From the perspective of site selection, then:

- a high degree of social acceptance makes the siting of WECS an attractive option. There may, however, be some planning and local visual impact concerns for both the individual, 10 Kw option and wind farm option.
- the modularity of wind turbines allows Ontario Hydro to add small blocks in capacity to match growth in demand and disperse the units to reduce transmission costs.
- there are a limited number of good sites in Ontario

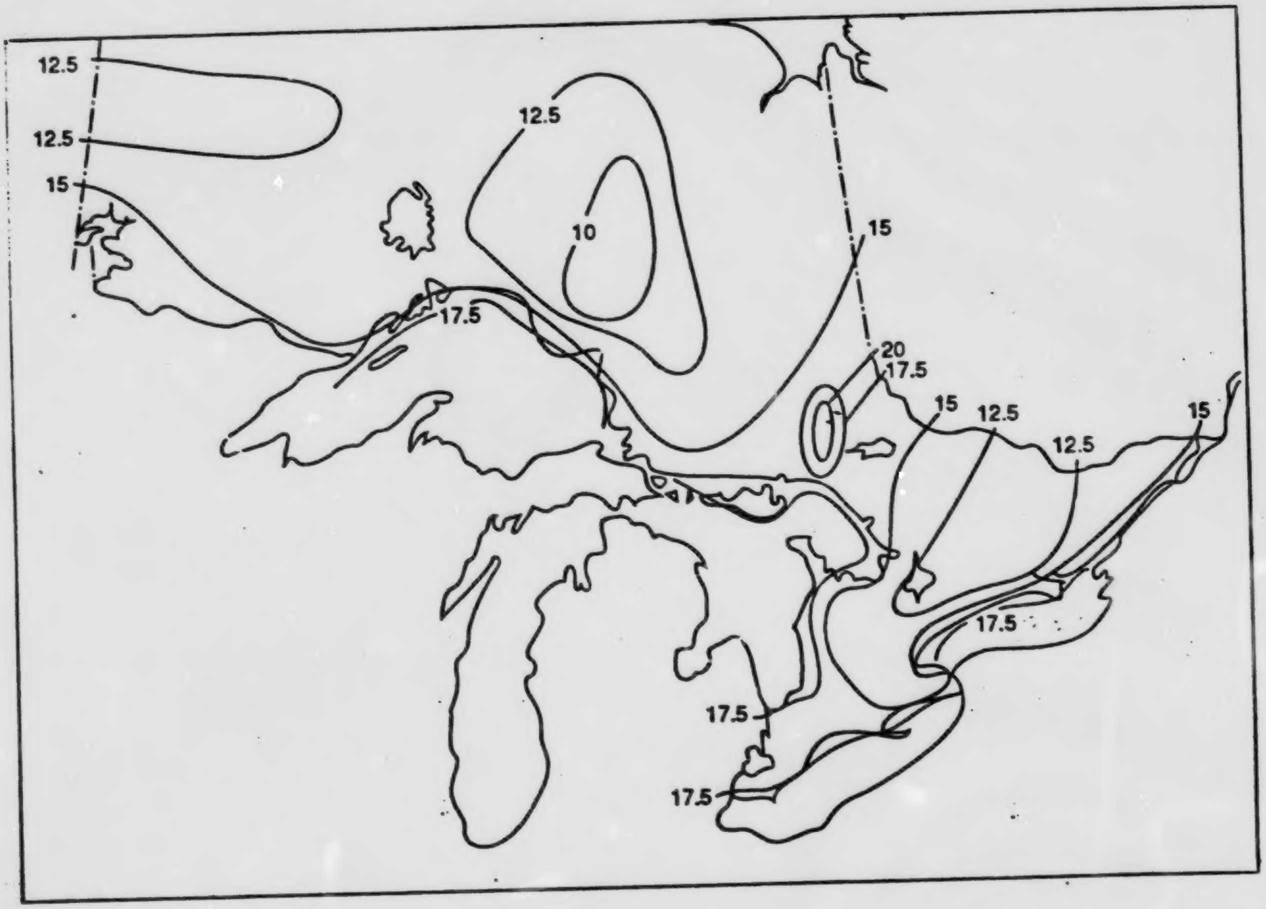

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FIGURE 2-2-2. Mean Wind Speed Map of Southern Ontario (Wind Speeds in km/h). [Courtesy, Environment Canada]

- the location of WECS, as wind farms, in some lake shore areas would create visual impacts and may be of concern to some groups, such as boaters, environmentalists. Possible impacts on birds may be a concern to birders and nature organizations.

Potential Mitigation Measures

- site selection away from built-up areas and bird migratory routes
- public education and information on WECS

MANUFACTURING

Potential Effects

We began by reviewing manufacturing effects potentially associated with WECS and considered two aspects: Would there be socio-economic impacts resulting from its manufacture? And, would there be socio-economic benefits associated with the manufacture of WECS in Ontario?

On the first point we assumed that any impacts associated with its manufacture would not involve unusual manufacturing processes and materials. We assumed that with any external social costs resulting from manufacture would be built into its price.[10]

On the second question, we noted that there is, at present, only a small industrial infrastructure[11] in Canada for the manufacture of wind energy conversion systems. And, there is not presently an industrial infrastructure regarding wind energy conversion systems in Ontario compared to localities such as California.[12] The existence of some facilities in Quebec, may preclude the need to build facilities in Ontario.

Without manufacturing subsidies/incentives or local supplier preferences, most of the components of a large WECS would be expected to be imported. Thus, there would be a societal cost (subsidies/incentives) to capture potential manufacturing socio-economic benefits such as the development of skilled jobs, higher payroll etc.

Potential Mitigation Measures

Ontario Hydro anticipates that WECS would develop as non-utility generation. Given that many WECS components are outside of the Province of Ontario, government support would be required to stimulate a manufacturing industry associated with WECS. With socio-economic incentives, the manufacture, installation and servicing of WECS may stimulate increased regional economic development in some parts of Ontario.

CONSTRUCTION

Potential Effects

Environmental impacts associated with WECS construction are likely to be similar to, but more clustered than, the construction of transmission towers[13]. Activities would be on a smaller scale and shorter in duration.

Workers would immigrate to a community with equipment for the duration of the construction period. Similar to transmission line construction, this would involve small crews of workers and equipment required for each of the phases of the construction period. Construction activities could involve the excavation of concrete footings, underground cables, installation of transformers and the use of heavy equipment for the erection of the generators. Construction skills would be standard construction trades. In addition:

- agricultural impacts could result from soil compaction and erosion.
- typical wind farm installations would involve the use of underground cable and dispersed ground-level transformers to deliver energy to the grid.
- terrestrial impacts of social importance would depend on local and regional land-use patterns and would be expected to be similar to or less than those associated with any other energy technology.[14]
- cable installation would use cut and cover techniques to avoid land compaction.
- compared to conventional generation sources, the would not be large numbers of immigrating workers, lessening the burden on local municipalities.

Potential Mitigation Measures

- precautions similar to the construction of transmission lines would have to be taken to minimize the impacts on the local ecosystems. Ontario Hydro would apply a thorough set of construction guidelines intended to avoid environmental impacts.
- soil compaction could be avoided through the installation and removal of construction roads

OPERATION

Compared to other energy forms, the operation of WECS poses relatively minor social impacts. Communities local to the wind farm may see the facility, hear it and may experience television and radio interference. However, foresight in siting and the use of appropriate materials may result in many of these effects being avoided. The impacts of the 10 Kw generator would depend on local siting characteristics.

The positive operational characteristics of WECS compared to other energy forms is the lack of primary and secondary social impacts resulting from the fuel source, ie compared to fossil and nuclear, there are no harmful waste products.

Potential negative impacts relate to reliability, cost, ability to meet changing load conditions and Ontario experience with this technology. "Wind is a renewable, but intermittent, energy source which may vary greatly over short periods of time. Ontario is not considered to be a windy area since average speeds range from less than 10 km/hr to about 20 km/hr."[15]

As a proven technology, wind energy has advanced greatly over the last decade. In 1990, there were approximately 2000 MW of wind energy capacity installed around the world.[16] Wind power technologies have made steady progress in the area of increased reliability, reduced cost and ability to operate at low wind speeds. Wind energy would provide employment for a small crew of highly skilled operations workers. However, in terms of reliability, wind is not dispatchable and there may be additional costs associated with the need for conventional generation reserve. Other potential operational effects include:

- it is assumed that 5 percent of the land would be occupied by the wind turbine and associated equipment[17]. Forest locations would involve clear-cutting. Some agricultural uses would be prohibited for agricultural locations.
- land under a wind farm could continue to be used for some agricultural pursuits such as grazing.[18]
- there are no aquatic emissions associated with the operation of WECS.
- there may be a health and safety risk should blade assembly fail
- noise and aesthetic impacts related to the location of wind farms may be important in some locales
- there may be potential for interference with television
- the potential exists for birds to collide with towers, rotors and transmission lines particularly along migratory routes[19] however, this effect can be avoided through careful site selection and mitigation measures

Potential Mitigation Measures

- the potential interference with television reception can be minimized through the use of non-metallic materials in the blades[20]
- the potential for blades to fail and be thrown hundreds of meters could be mitigated through regular inspections and maintenance to reduce this hazard.
- localized visual and noise impacts would be localized and could be mitigated with appropriate siting and design
- siting and other measures could be used to avoid effects on birds.

MAINTENANCE AND DECOMMISSIONING

The socio-economic impacts of the maintenance and decommissioning of WECS are expected to be minimal. A wind generator should last as long as it is maintained. There are no unusual or hazardous parts or components inhibiting recycling.

- a single maintenance crew should be able to service 20 to 25 machines. Local employment, however, would be minimal as large wind turbines would require expert maintenance of both the electronic and mechanical systems.[21]
- dismantling of wind turbines would be similar to the impacts of the dismantling of transmission towers.[22]
- recycling the remaining components would present minimal unusual or hazardous disposal problems.
- land used for WECS could be returned to its previous use.

OVERALL ASSESSMENT OF THE SOCIO-ECONOMIC IMPACTS OF WIND ENERGY CONVERSION SYSTEMS

The overall socio-economic impacts of WECS in the context of the socio-economic criteria listed earlier and possible opportunities and barriers to implementation are summarized below:

Barriers

- without specific policies stimulating the development of a Provincial-based wind energy manufacturing industry, regional employment and economic development is expected to be limited to activities and spinoffs associated with construction, operation and maintenance

- cost estimates provided by others[23] indicate that wind energy sources are currently not economic sources of generation for bulk electricity systems in Ontario. However, public support exists for socio-economic incentives for some energy systems that have less environmental impact.

- there are a limited number of good wind sites in Ontario

- WECS provide intermittent availability of power

- significant amount of land may potentially be required for large wind farms.

Opportunities

- wind power has generally enjoyed a high level of social acceptance

- with socio-economic incentives referred to earlier, the manufacture, installation and servicing of WECS may stimulate limited regional economic development

- WECS have no air emissions, no fuel costs, minimal harmful waste products, land used for WECS could be returned to production, it is a modular and renewable fuel source that is environmentally benign. The Worldwatch Institute considers wind power as a technology that would contribute to the reduction of global warming.[24]

CONCLUSIONS

This socio-economic analysis came to several conclusions regarding the implementation of WECS in the context of the Province of Ontario.

1. The interest in wind turbines for utility application arises largely because of their negligible emissions to the environment and their use of a renewable energy source.

2. Environmentally attractive features, (such as the lack of harmful waste products, use of a renewable source of fuel), of wind based electricity generation have resulted in a significant degree of social acceptance of this energy option.

3. Without specific policies stimulating the development of a Provincial-based wind energy manufacturing industry, regional employment and economic development is expected to be limited to activities associated with the construction, operation and maintenance of wind facilities.

4. The socio-economic impacts due to manufacturing, construction, operations, maintenance and decommissioning are expected to be minor, avoidable or mitigitable

5. The Alternative Energy Review concludes the potential for wind power in Ontario is limited by the availability of sites having suitable wind-speeds and its high cost. It also suggests that wind power is making steady progress as the reliability of components is increasing as with more efficient electricity production.

6. There may be aesthetic impacts, as Ontario's windiest sites are located along the Hudson's Bay coastline and along the westward facing shores of the Great Lakes. This may be of some concern to social groups.

Finally, as this was a research study based on secondary data and interviews, a full research study of potential socio-economic effects of WECS in Ontario is required.

ENDNOTES

1. Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. i

2. Ontario Hydro, Alternative Energy Review, Draft, September, 1991

3. Ontario Hydro, Demand/Supply Plan Report, December, 1989.

4. Note, some of the text of this paper duplicates the text of the Alternative Energy Review. References have been made where specific technical conclusions have implications for social effects.

5. Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. i

6. Public consultation research is referenced in several Ontario Hydro reports including: Meeting Future Energy Needs - Provincial Organization Consultation Program, Summary Reports, Vols. 1, 2 and 3, April/May 1986; Meeting Future Energy Needs - Regional Consultation Program, August, 1986; Meeting Future Energy Needs - Regional Consultation Program, Participant Questionnaire Results, August 1986.

7. Ontario Hydro, Environmental Analysis, December, 1989, ppgs 3-5.

8. Ontario Hydro, Alternative Energy Report, Draft, September 1991, p. 41

9. "Because energy production by wind turbine is extremely sensitive to wind speed, Figure 2-2-2 should not be used to assess the wind energy potential of specific sites" Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. 41

10. Ontario Hydro, Alternative Energy Review, Draft, September, 1991. p. 53

11. See Table 2-4-3 of the Alternative Energy Review, describing aspects of large Canadian wind turbine installations.

12. However, "10 150kW vertical axis turbines are being built by Adecon, an Ontario-based manufacturer for a wind farm in the area of Pincher Creek, Alberta." Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. 50

13. Ontario Hydro, Alternative Energy Review, Draft, September, 1991, Chapter 2.0 p. 53. Social impacts of transmission line construction have been discussed in: Social Impacts of Transmission Facilities, Analysis and Case Studies, J.C. Boyer and D. R. Hardy, Ontario Hydro Report 80114, April, 1980.

14. Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. 53

15. Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. v

16. Ontario Hydro, Alternative Energy Review, Draft, September, 1991, p. 48

17. Swisher, R., Wind Energy Comes of Age, Solar Today, May/June 1991, as quoted in the Alternative Energy Review

18. Swisher, R., Wind Energy Comes of Age, Solar Today, May/June 1991

19. Swisher, R., Wind Energy Comes of Age, Solar Today, May/June, 1991, as quoted in the Alternative Energy Review, op cit, p. 53

20. Solar Assessment Program: Environmental Factors, Energy Research and Development Administration, ERDA, 77-47/3

21. Ontario Hydro, Alternate Energy Review, Draft, September, 1991, p. 54

22. Solar Assessment Program: Environmental Factors, Energy Research and Development Administration, ERDA, 1977

23. Ontario Hydro, Alternative Energy Review, Draft, September 1991, "The results indicate that solar, wind, fuel cells, biomass and peat options assessed are not currently economic compared to conventional generation technologies for Ontario." p. ii

24. Worldwatch Paper #91, Christopher Flavin, Slowing Global Warming: A Worldwide Strategy, October, 1989

Renewable Energy: So What If It Works In California?

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Presentation to the

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New York

September 5, 1991

Renewable Energy: So What If It Works In California?

Introduction

I thought I would call this talk "Everything You Need to Know to Make a Fast Fortune In Renewable Energy." But I was sure one of my colleagues here would cover that.

So, instead, I thought of examining the relevance of experience with renewables in California during the '80s to other areas and other economies.

Why? Because California accounts for 80% of U.S. electricity production from non-hydro renewables. Something is going on in California that may be worth examining.

My main thesis is: a full understanding of the California experience is the best available guide to investing in renewable energy in the future. But, as you may infer from my title, there is a legitimate question as to how much of our California experience is relevant to other markets. Some of it definitely will be; some probably will not be.

A Definition of Renewable Energy

Let me start with a crude and deliberately broad definition of renewable energy in terms of what it is not, i.e., it is not energy extracted from fossil or nuclear fuels.

Diversity in Options and Opportunity

Renewable options are differentiated not only in terms of technology attributes, but also in terms of the types of investment opportunity they lend themselves to.

Renewable technologies bear little family resemblance to one another as investment opportunities. They are all "capital intensive" to be sure, and their economics are all quite sensitive to the quality and availability of the "free" fuel they use. But basic renewable resources are different and compel different approaches to resource conversion. Some technologies are capable of continuous operation, while others are inherently intermittent. Resource availability varies from year to year in some cases, seasonally in others, day to day in others, hour to hour, and even momentarily in others.

Renewable energy is a meaningful grouping in the context of national energy strategy and certainly in the public eye and consciousness. To the extent that national policy and public opinion have the effect of promoting or discouraging types of investment, it makes sense to discuss investment opportunities under the category "renewable." But in the context of investment opportunity, to say nothing of utility planning, generalizations about renewables have far more potential to mislead than inform.

The types of investments carry with them significantly different risk profiles, time horizons, etc. By way of illustration, the major opportunities of the '80s were **project investment** opportunities, e.g., the more than $2 billion invested in California windfarms. Also important in this timeframe were **technology investments**, notably the hundreds of millions of dollars invested in the research and development of competing photovoltaics module technologies. Less conspicuous but also substantial were the **investments in manufacturing capability** necessary to support wind and solar thermal projects, and the growing market activity in photovoltaics. Technology and manufacturing investments were made in other key technologies - biomass, geothermal, and hydroelectric - but in these cases project investments predominated.

A fourth type of investment, even less conspicuous, deserves mention, i.e., **corporate and market development investment**. In early years, companies whose focus is renewables lack market power in dealing with suppliers of necessary equipment and services. Established companies in established markets are able to negotiate lower prices and better delivery schedules. The most venturesome renewables companies quickly discovered that the energy market demands a fully supported and integrated approach to products and projects. Indeed, the success stories to date have been companies who chose this path. LUZ, for example, in the solar thermal business, developed the new technology, designed the power plants, developed projects, managed their construction and took responsibility for operation and maintenance. So did U.S. Windpower in the wind business. The market was a market for power, not a market for wind turbines, solar collectors, or other disaggregated goods and services. The companies who made a total commitment to their sector of the renewables market and invested in integrated corporate capabilities succeeded in markets that larger and stronger companies dared not attack, even with superior technology. However, failed corporate and market development investments were many. The attributes of success were integration and commitment.

The '80s Transition

I will not attempt to summarize the legislative, regulatory, and market interventions that account for recent renewable energy development in California. Most have been withdrawn, superseded or modified, and, moreover, certain renewable technologies have matured tremendously since these interventions took effect. Nevertheless, the net result, summarized for the PG&E system in Table 1, is important and revealing.

Clearly, some new renewable technologies have come into play, i.e., wind, and solar thermal (not indicated in the table because it happened in Southern California). Incremental additions to already significant hydroelectric, geothermal, and biomass development also occurred. Central station photovoltaics deployment culminated in a single relatively small (several MW) project, but significant remote/specialty power market penetration occurred, that was economically driven and unleveraged by the interventions mentioned above.

The numbers suggest limits more clearly than trends, especially if viewed in the context of prior history. For example, in an average year more than 40% of PG&E's delivered electricity comes from hydroelectric and geothermal sources. Why was so little new capacity added during the '80s? Why so little photovoltaics? Why only 300 MW of solar thermal? And this only in Southern California? Why not more biomass and municipal waste? What are the key limiting factors? Right now (and you can be sure technical progress and future interventions will change some of this), the key limits are:

1. Hydroelectric development is judged against much more stringent criteria than in the past. Permitting risks are prohibitive, even for remaining economically developable sites.

2. Additional geothermal production requires control and development of underground resources that are less extensive and not yet well characterized, resulting in typically unacceptable resource risks.

3. In spite of impressive progress, photovoltaics is still well outside the economic range for central generation; meanwhile, the solar thermal industry consists of one company bringing one marginally economic new project on-line each year under contracts signed with one utility several years ago. The market for stand-alone photovoltaic systems is growing rapidly but is still small.

4. Economical biomass fuel is primarily a byproduct of forestry and farming, and the supply of such fuel has already been fully, if not overly, subscribed.

Table 1.

Pacific Gas and Electric Company

Summary of Qualifying Facilities Projects
First Quarter 1991

Project Type	Signed Contracts					Projects Under Active Discussion	
	Operational			Not Yet Operational			
	Number of Projects	Nameplate kW	Oper Size kW	Number of Projects	Nameplate kW	Number of Projects	Nameplate kW
Cogeneration	176	2,630,149	2,536,883	29	1,239,656	28	449,677
Solid Waste/Biomass	56	615,358	595,410	4	39,750	4	24,650
Geothermal	8	152,700	149,900	0	0	1	25
Solar	8	16,050	4,629	0	0	0	0
Wind	112	1,056,230	846,219	6	480,112	1	60,000
Hydroelectric	112	218,069	218,001	15	25,625	38	63,214
Total	**472**	**4,688,556**	**4,351,042**	**54**	**1,785,143**	**72**	**597,566**

5. Wind development has concentrated in the largest, most developable and strategically located siting area in our service territory, the Altamont Pass, which is now almost completely, though certainly not optimally, developed.

Opportunities to Optimize in California

Creators of investment opportunity will be those who move these limits aside. The renewable industries and the projects of the '80s may need to be reoptimized in the context of the emerging markets of the '90s.

For example, existing geothermal, biomass, and wind power plants, for different reasons, have been designed to economic criteria that undervalue the renewable "fuel." When there were small, uncertain, or non-competitive markets for wind rights, geothermal steam, and forestry wastes, the markets undervalued these commodities. When they are reappraised, there will be money to be made in reoptimizing the facilities that convert them. This may be more opportune then tapping new but lower grade resources with new facilities. Investments in resource conversion efficiency may be more economic than investment in additional resource development. This is an extension of the current integrated resource planning thesis that says customer efficiency investments may be more economical than supply system expansion.

Likewise, '80s solar thermal technology was selected by its developers for its near-term risk profile rather than its long-term "learned out" economic superiority. Maybe solar thermal can be significantly more cost-effective, if intrinsically more economical designs are proven and brought to market.

Finally, if photovoltaics cannot compete in bulk power markets, why not concentrate on the markets where it could be the economic choice? Such markets are developable, as are the products that would meet their requirements.

A Few Common Threads

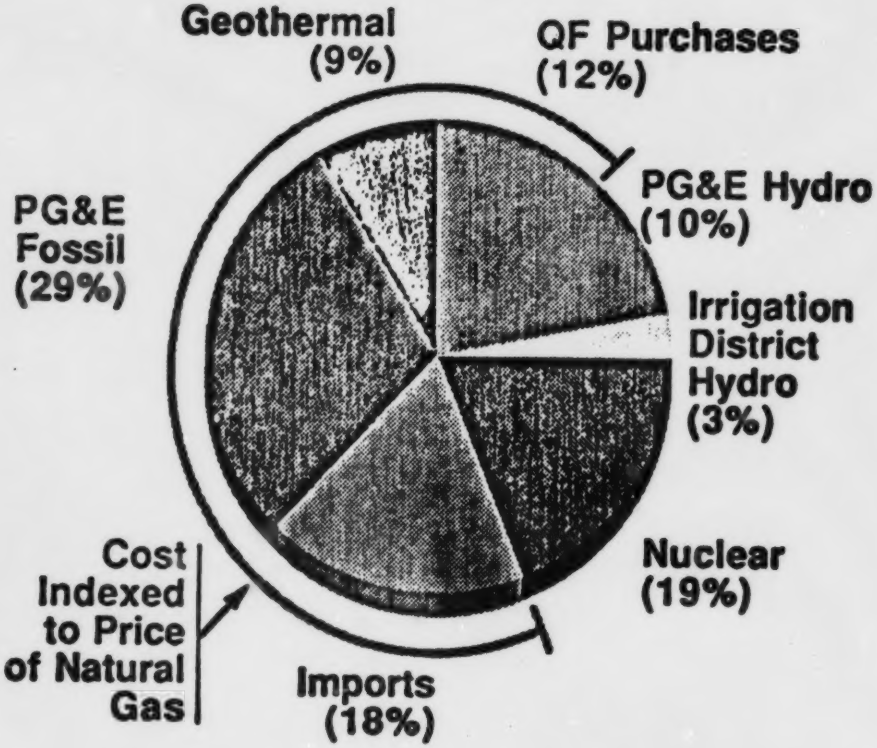
Much experience, insight, and relevant information is aggregated in the numbers of Table 1, and I have indicated how the unique attributes of individual technologies limit investment opportunity. Earlier, I cautioned against generalizations. But some common threads of experience and insight from the eighties are too important to ignore; and I will risk my promising future as an investment commentator by saying what I think they are.

1. The only rule is uncertainty; the only trend is diversity. It was a penchant of the '70s to try to pick winners in the game of energy options. For most utilities, resource diversity meant using not only coal but some other type of fuel or resource as well. Table 1, taken together with Figure 1, PG&E's overall resource mix, suggests a new, more robust concept of diversity that may well be the antidote to the likely perils of picking winners. Renewable sources not only add diversity, but their economic attributes are typically more predictable then fossil and nuclear fuel-based options. This "fuel risk" is mitigated, if not eliminated. A portfolio approach to electric resource planning is clearly indicated by the market turbulence, policy instability and price/demand uncertainties facing utilities. Every utility in the U.S. has at least one renewable option that could strengthen its resource portfolios.

2. Sustainable is more important than renewable. For example, at the Geysers, we have a major high quality geothermal resource that is literally running out of steam, being boiled dry. The geothermal heat is renewable on appropriate time scales. But the resource has been overdeveloped in relation to natural processes of water replenishment, and artificial replenishment has been too little, too late. Likewise, as alluded to earlier, there are limits to supplies of biomass and municipal waste fuel, so that unrestricted development of conversion

PG&E's Sources of Electric Energy

1990 Recorded



Factors influencing our selection of new resources:

- Capital Cost
- Fuel Costs
- Dispatchability
- Fuel Diversity (Security)
- Contingency Reserves
- Cost Diversity
- Environmental Impacts

PG&E

FIGURE 1

915338/G768

facilities can result in under-utilization of equipment assets due to fuel shortages. Whether production of biomass as an "energy crop" per se can be done on a truly sustainable basis in the context of land and water use priorities, soil nutrient depletion, etc. is a critical and unresolved issue.

3. Perception lags reality by about five years. I do not know exactly why this is true, but it seems like sort of an "industry average." A good illustration is the perception of wind widely held in the utility industry a few years ago, i.e., that wind technology would always be uneconomical, insignificant, and otherwise ill-suited to utility needs. This was once true, but it ceased to be true about five years ago. Only now is there an emerging recognition that wind may be an option worthy of consideration. What is actually true now is that wind will shortly be an economically preferred option where good resources are available. If my thesis is correct, this fact will be widely perceived within the utility industry somewhere around 1996.

4. Value is just as important as cost. This is best illustrated by the fact that solar thermal power plants whose energy production costs are still non-competitive have nevertheless entered the market. How could this happen? It happened because their developer designed them to capture maximum value at least cost, optimizing the natural gas augmentation of the solar boiler to obtain additional credit for capacity. The advocates of photovoltaics are now building their strategy on a similar foundation, realizing that the location-driven value of a "distributed" photovoltaic system can be of the same magnitude as its energy and capacity benefits to the electric system as a whole. To a small industry, penetrable niche markets may be recognized as more important than the large-scale markets that dance in the heads of policy makers.

5. Renewable energy is real and it matters. The eighties were a decade of at once ignoring and at the same time beginning to acknowledge global limits, and global interdependencies. The ozone layer. The greenhouse effect. Chernobyl. The widening gap between industrialized and developing countries.

   A dual invitation to self-destruction is before us. Ignore the global environment and doom future generations to crisis and calamity. Ignore the legitimate aspirations of the majority of the world's population and abandon hope for world order.

   For the majority of the world's population, the nuclear option is inappropriate if not irrelevant. For the remainder of the world to reach even our current level of national prosperity by commensurate use of fossil fuel, the consumption of fossil fuels and production of greenhouse gases would have to increase by a factor of ten.

   By process of elimination, therefore, renewables will be an extremely important tool in moving toward a sustainable energy supply on a global basis. Fortunately for the the planet and its future population, renewable energy options are real and increasingly economically competitive.

So What If It Works in California?

In preceding sections I talked about our recent renewables experience in California, and its implications for our planning for the '90s. How much of our experience is relevant to renewable investment opportunities in markets outside California? In what context? Will we be leaders in the future? Or will renewable development activity elsewhere take precedence? These are questions worth debating. Here are some comments in lieu of answers.

Recent California experience with renewables investment is unlikely to be precisely replicated elsewhere. California is a wealthy state in a wealthy country, and we have conducted an experiment in renewables which was, by any standards, extremely expensive. Moreover, in the

U.S. we can afford sophisticated equipment, and we can train people to use and maintain the equipment because the needed support is only a call or fax away. Note, however, that our experiment did not yield a particularly robust U.S. renewables industry. Many companies that gained successful and relevant experience through early California projects have abandoned the field because of uncertain near-term market prospects. Many other companies folded because of technical and financial difficulty. It is doubtful whether this pattern will be appropriate in other countries or even other states in the future.

A related point is that a relatively expensive phase of resource exploration and characterization must precede resource development; this is no less true in renewables than other natural resources. The stage was set for renewables development in California during the '80s by a substantial prior investment in good resource data. By contrast, most utilities, even in the U.S., have not fully scoped out the renewable resources in their areas. Obviously, this is both a market barrier and an investment opportunity of sorts.

The best strategies will be long-term strategies. The enactment of the Public Utility Regulatory Policies Act (PURPA) created short-term investment opportunities in the U.S. and California, in particular. The renewable technologies that emerged successfully in the U.S. market were optimized relative to our industrial base, our utility infrastructure, and the extremely unusual and transient pricing/purchasing criteria that forced utilities to buy unlimited renewable energy on a non-competitive basis. It is an experiment that will not be repeated, even in California. Given the economic inefficiency of the approach, the short-term investments typical of the 1980s in California will be the exception rather than the rule in future international renewables development. Renewables will be a significant growth industry, but dabbling and speculation will not likely be rewarded.

Anticipation and vision will be more helpful than spreadsheets. The type of investment that will open up all of the other types of investment opportunities is the type that I characterized earlier as corporate and market development. It is clear that renewable technologies will in some cases compete with fossil fuels in existing markets and in other cases will open up entirely new possibilities for energy infrastructure development. For example, a pattern of electrification appropriate to developing countries may be the incremental deployment of stand-alone renewable based "mini utility" systems. These hybrid power systems may or may not eventually be interconnected but will be capable of providing reliable service even though not a part of a large grid. It is even imaginable that a source of investment opportunity in the future may come from allowing industrialized countries to clean up their existing fossil and nuclear-based infrastructure gradually, in return for their investment in the deployment of renewable-based new generation systems in countries where electric supply infrastructure is still relatively undeveloped. I offer this primarily to illustrate the flexibility and initiative that may be required to capture renewable energy investment opportunities in the future. On the other hand, it might just be a rational approach to the challenges we face as small shareholders in Earth, Ltd.

BRIDGING TO ENVIRONMENTALLY PREFERRED TECHNOLOGY:

A Perspective on Utility Wind Integration

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October 15, 1991

Abstract

PG&E is building its electric resource strategy on the foundation of customer, utility, and regional efficiencies, while working toward an efficiently structured competitive market for electric supply. PG&E's system can meet near term needs without expansion. However, we anticipate gradual retirement of existing units combined with load growth pressures that efficiency cannot totally offset. After careful evaluation of available and potential options, it appears that future needs can be met in an environmentally and economically sound manner, provided certain emerging technologies are brought to the point of commercial readiness during the 1990s. This will require acceleration of research, development, and demonstration efforts for the targeted technologies.

Accordingly, a technology acceleration initiative is being planned that would address selected technologies in three categories: 1) Renewables, 2) Advanced Natural Gas Conversion, and 3) Distributed Generation and Storage. Its goal is to provide PG&E and the Pacific Coast region with a robust portfolio of options tailored to regional indigenous resources and existing electric supply infrastructure. The technologies targeted within these categories are at varying stages of technical, economic and market readiness. However, in each case there is a substantial base of technology to build upon and a clear opportunity to design and demonstrate utility grade systems over the next ten years.

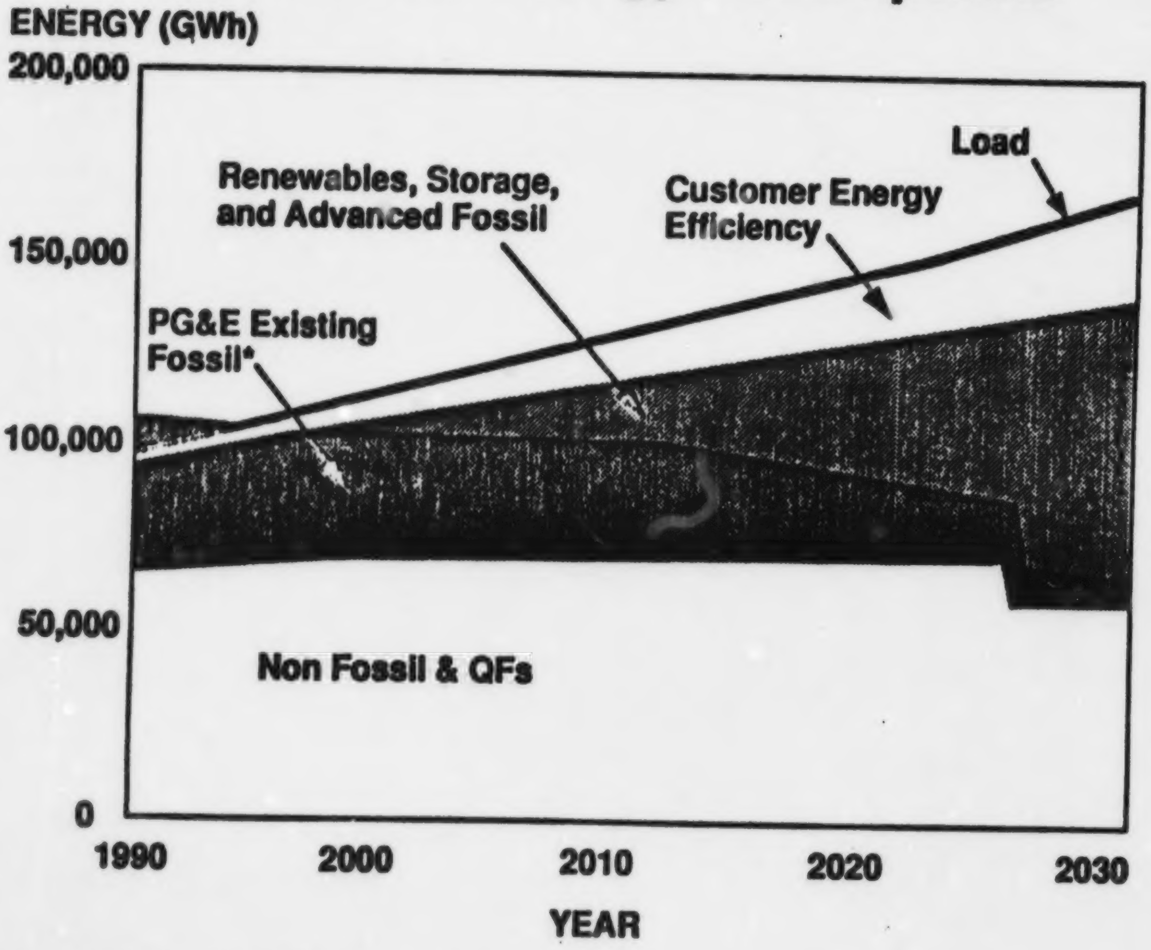
I. Introduction - Long Term Resource Planning Context

As illustrated in Figure 1, the following considerations frame PG&E's outlook toward future electric energy supply:

- Based on critical-year energy analysis, PG&E will have to start adding new resources by the early 2000s, possibly earlier, if certain contingencies occur.
- Customer Energy Efficiency (CEE) will be used to its maximum economic potential to meet these growing needs. However, because high benefit/cost CEE will be captured first, long-term CEE additions will be more difficult to obtain than those in this decade and will have declining incremental benefits.
- Current forecasts for load growth do not account for electric transportation market development, nor for dislocations in the supply of energy from non-utility owned power plants (Qualifying Facilities [QFs] or Independent Power Plant [IPPs]).
- To a limited extent in the 1990s, but to a large extent after 2000, our existing fossil plants will reach the point where retirement or repowering is economically justified. This will allow PG&E to improve operating efficiency, avoid high O&M costs, and to meet stricter air quality standards.
- As we approach the year 2000, PG&E will begin making investment decisions for large quantities of generation additions or purchases from QFs/IPPs. Once investment or purchase decisions are made, the new facilities will need to operate over their 30-40 year economic life to recover investment. It will be advantageous to PG&E to have resource options with low environmental and fuel supply/price risks to deploy in that period.

By comparing two conceptual capacity expansion scenarios, the challenges ahead can be placed in perspective. In one scenario, decisions are driven by traditional criteria, i.e., present value economic analysis. In the other, environmental concerns are also given weight.

Vision 2030: PG&E Resource Plan
Critical-Year Energy Assumptions



*Includes 4000 GWh of Emergency Spot Purchases

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Figure 1

In the economic expansion scenario:

- If PG&E were to call for bids today to meet its anticipated generation needs for the years 2000-2010, most of the winners would probably be current best available technology fossil-fired units (cogeneration and combined cycle/repowering). Wind would probably comprise the only renewable technology and might capture only a small share (see *Figure 2*).
- Concerns regarding the environmental performance could bring operating and/or economic problems during the life of the traditional units.
- Increased dependence on fossil fuel implies a risk of vulnerability to supply and price uncertainties.
- Uncertainty about meeting future air quality standards implies an environmental risk.

In the environmental expansion scenario:

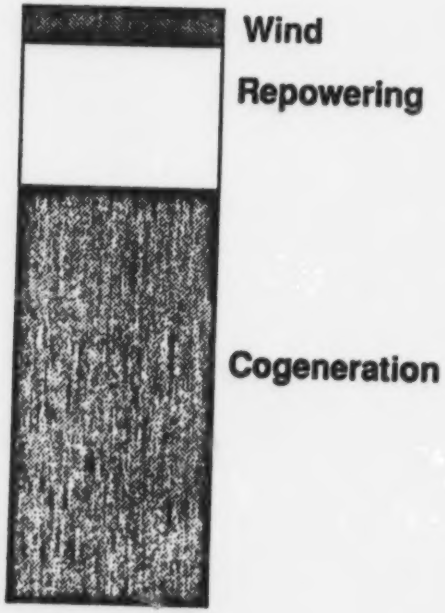
- Renewable technology has already progressed to the point that PG&E could meet a significant amount of future capacity addition requirements with renewables. However, further technical advancements are required to achieve cost reductions that increase the diversity of the renewable resource mix (see *Figure 3*).
- If regulators were to place significant weight on environmental attributes in resource selection *today*, ratepayers might incur a 20-25% premium on prices paid for renewable technology.
- For solar technologies, the premium could initially be even larger.
- As technologies advance over the next 10-15 years, this premium will decline. But without an accelerated effort by PG&E and others the premium will still be significant, probably more than 15%.

II. Strategic Response

The energy demands of Northern and Central California are growing at over 2 percent per year. Unmanaged, this growth would require us to deliver 25% more energy to our customers in the year 2000 than we did in 1990. PG&E's electric energy growth needs through the 1990s can be met through the aggressive pursuit of efficiencies -- improvements in customer energy efficiency, existing generating system efficiency, and regional operations efficiency. Through this approach, we intend to cut our energy growth by half and our peak demand growth by 75% (2500 megawatts) at a cost significantly less than the levelized cost of building new fossil generation. Nevertheless, like many other utilities, PG&E will need significant new supply-side resource additions early in the next century. Although aggressive customer energy efficiency programs will continue to be the mainstay of our strategy for the forseeable future, electric loads will continue to grow beyond our ability to offset them through efficiency measures, and portions of our existing system will need replacement due to service life considerations.

While our existing system and efficiency plans provide a solid bridge to the future, what awaits on the other side of the bridge is a need to expand and rebuild utility infrastructure. As outlined above, this presents a dilemma, i.e., that currently economic generation options are not environmentally preferred, and environmentally attractive options are not yet cost effective and/or proven in utility service. If, as we hope and expect, society chooses the

Economic Capacity Expansion Scenario
2000 - 2010



Likely mix given today's technologies

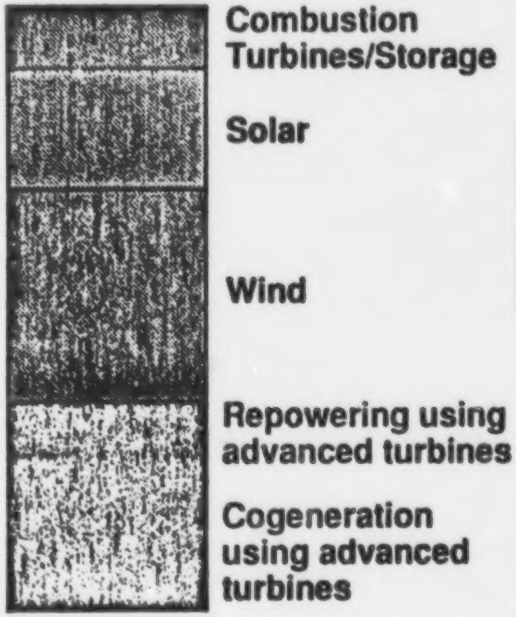
Risks

- May not meet future environmental standards
- Further dependence on fossil fuel (= price risk)

91-1-11

Figure 2

Environmental Capacity Expansion Scenario
2000 - 2010



Risks

- **Higher than traditional economic energy price**

Likely mix with large environmental premium

91-1-11

Figure 3

course of environmental stewardship, an economic premium will have to be paid to implement an environmentally preferred resource mix. We have been exploring steps that can be taken to significantly reduce this premium. As illustrated in *Figure 4*, the key strategies we have identified are discrete but also synergistic. Specifically:

- Given the objective of having generation options that the are both economically and environmentally preferred, PG&E must take action in the 1990s to advance targeted technologies.
- To bring about competitive options, PG&E will need to employ both technology push and market pull strategies.
- The distinction between technology push and market pull lies in the type of learning required.
    - Technology push includes laboratory development, scaleups with substantial risk, and early demonstrations.
    - Market pull focuses on cost reduction through incremental "market-driven" innovation.
- The targeted technologies are modular and based on economies of mass production, not economies of scale. Experience in use is rapidly translated into product improvements that lead to additional cost reduction (organizational learning).
- The third strategy involves competition. Though PG&E will undoubtedly invest in new generating facilities of its own in the future, we expect to be a major purchaser of power from the independent energy community. Our customers will benefit if power comes from diverse suppliers who sell power at fully competitive prices, with timing and controllability that result in traditional levels of service reliability. Legislative and regulatory changes will be needed to foster this true competition.

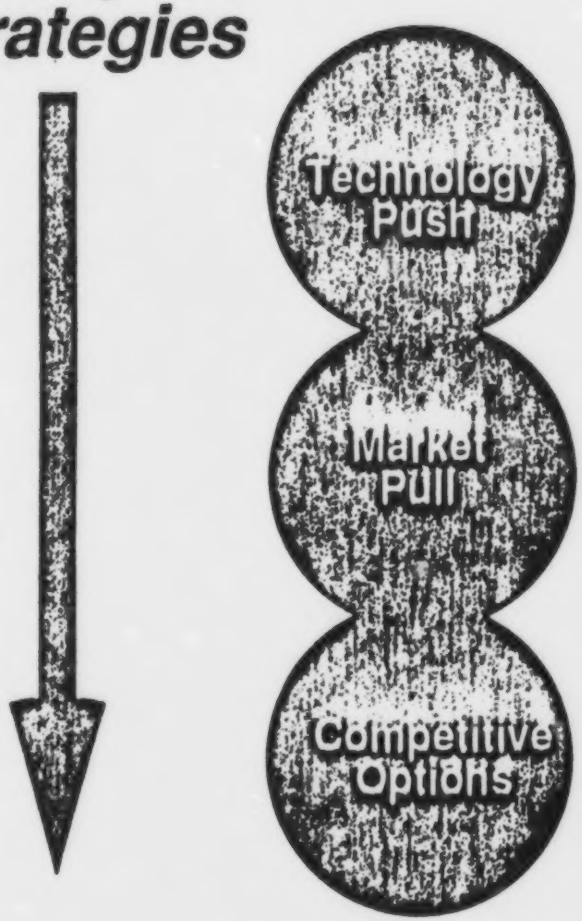
III. Technology Acceleration

We have made significant progress in identifying what can effectively be done to implement the technology push strategy. We plan to bring clean renewable energy and high efficiency natural gas conversion technologies to the point of readiness for cost-effective deployment in PG&E's service territory after the year 2000. Our initiative involves phased implementation of cooperative demonstrations of emerging technologies between now and the year 2000.

Our **goal is to acquire a robust portfolio of viable clean electric supply options** by the end of the ten-year initiative. Robustness is assured by addressing multiple technology opportunities applicable to three key market trends:

1. Renewables. There are downward trends in the cost of intermittent renewable supply technologies. The need to broaden generation options, combined with environmental preferences, will lead to a competitive advantage for renewables in the future.
2. Advanced Gas Conversion. The aging of PG&E's fleet of fossil plants, combined with expected increases in natural gas prices, tighter emissions limits, and the anticipated availability of highly efficient conversion systems, may compel economic retrofitting of our existing sites with such systems.

Key Strategies


Technology Push
Market Pull
Competitive Options

Prove technologies

Nurture emerging industry capability

Provide robust portfolio of clean cost-effective technologies

91-1-11

Figure 4

3. Distributed Generation and Storage. The continued improvement of modular generation and storage technologies, combined with increasing power distribution costs and advances in information, control, and demand side technologies, may economically motivate development of distributed generation and storage markets.

The potential impact of these trends on the evolution of the PG&E electric system is suggested in Figure 5.

In this context, the viability of a particular technology will depend on whether:

1. The primary resources it captures or converts are abundant.
2. Its current technical risks and uncertainties can be resolved over roughly a ten year development period.
3. The potential for cost-effectiveness over the early decades of the next century is well established.
4. A competitive technology delivery infrastructure can be put in place.
5. The overall market for the technology is sufficient to support the necessary infrastructure.
6. The technology fits in with long-term PG&E system needs and planning scenarios that reflect substantial uncertainty.

Technologies are emerging that will meet these tests of viability. They differ significantly in the steps required to achieve viability in the desired time frame. Thus, our plan requires a separate strategy in each case. For those technologies that have been targeted in the plan, an indication of the technology-specific nature of the challenge ahead is suggested in Figure 6.

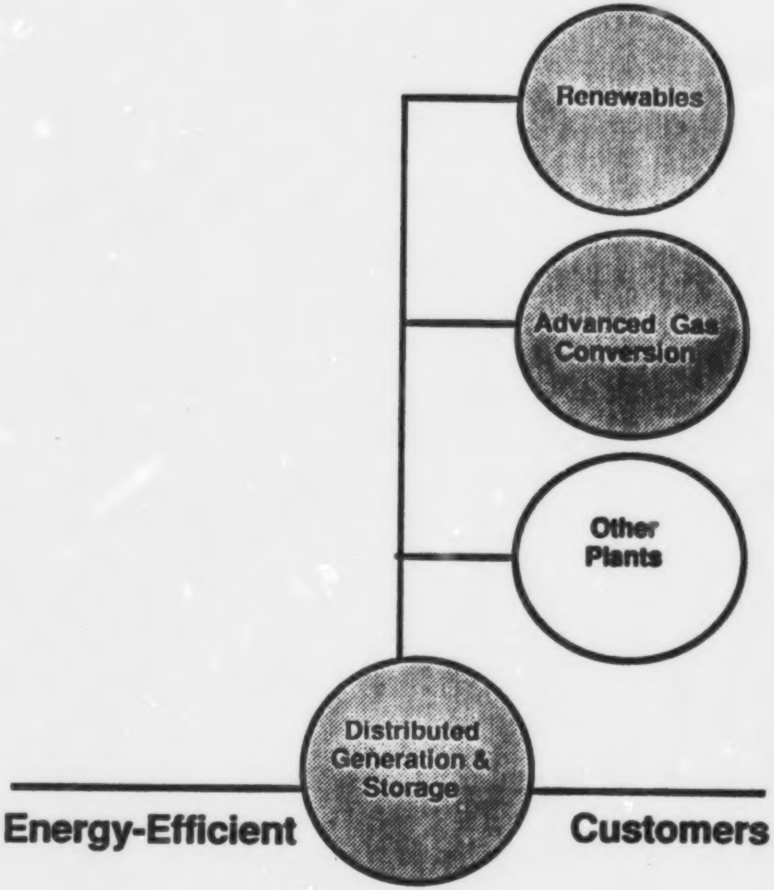
In general, none of the targeted technologies or systems can be characterized as viable today. They are not technically ready for significant levels of cost-effective application. At the current pace of development, their full viability by the end of the decade is problematic. There is well documented progress, but prevailing market uncertainty, combined with the current weakness of embryonic vendor infrastructures and supporting R&D programs, is likely to impede further progress and, in some cases, may even place key technology supplier organizational capabilities at risk. PG&E, as a financially and technically strong utility, is in a position to leverage our position and accelerate technology readiness in selected cases through carefully designed projects and complementary business and regulatory initiatives.

IV. Technology Strategy - Renewables

PG&E's service territory includes high quality wind and solar siting areas, and as an outcome of standard offer contracts and subsidies, both wind and solar thermal trough technologies are approaching the economic range. There is a synergy between the two technologies that needs to be better understood. Both resources are intermittent, though solar thermal (in natural gas hybrid or thermal storage configurations) is dispatchable. Even without this feature, wind and solar thermal match PG&E's system needs well, as illustrated in *Figure 7*. Even so, the match is not perfect, nor are future system load shapes entirely predictable, which suggests that when penetration of these resources into PG&E's mix has reached significant levels, additional system storage beyond the 1000MW currently

Vision of the 21st Century

Cleaner PG&E of the Future



Renewables

Advanced Gas Conversion

Other Plants

Distributed Generation & Storage

Energy-Efficient Customers

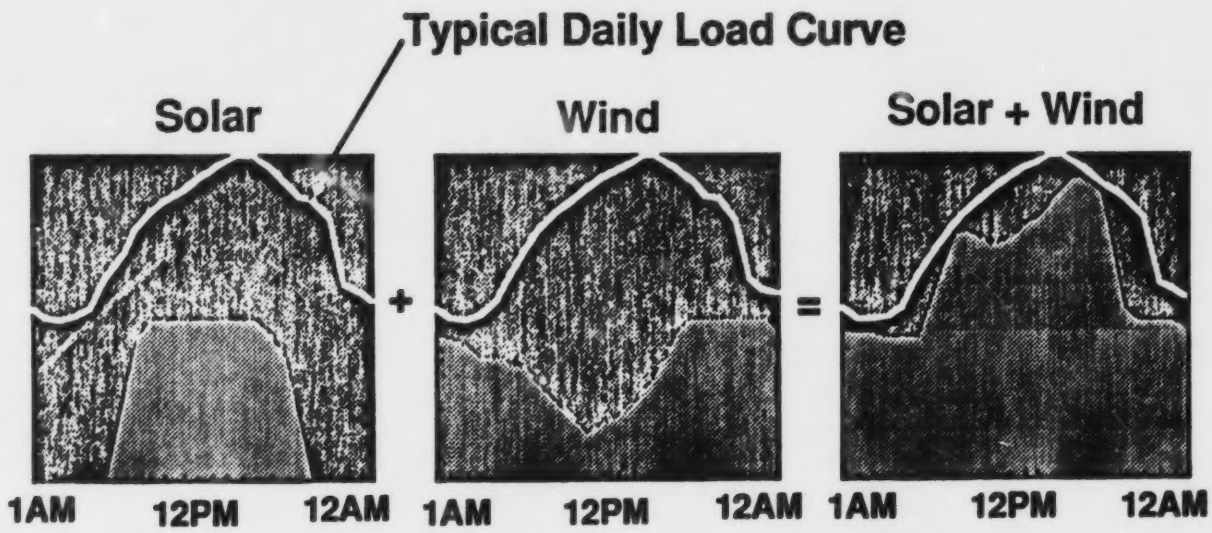
Figure 5

Major Emerging Electric Supply Technology Challenges

	Resource Availability/ Permitting	Technology Advancement/ Risk	Long-Term Cost-Effectiveness of Current Technology	Today's Industry Strength/ Competition	Market Development
Renewables	√			√	√
Advanced Gas Conversion		√			√
Distributed Generation and Storage			√		√

Figure 6

Solar and Wind Energy Production Match PG&E Load



91-1-11

Figure 7

installed will probably be needed for optimum economic operation of PG&E's system. The PG&E service area has abundant sites for a technology that involves using off-peak electricity to compress air for storage underground and later use in avoiding compression losses in a conventional combustion turbine. Compressed air energy storage (CAES) may provide PG&E with a strategic tool to optimize purchases of power and overall system operation long term, while providing a service of significant value to wind and other non-dispatching QFs. Implementation of these technologies will also be aided by the development of automated control strategies for more efficient operation of resource mixes. The synergies among the above renewable and storage technologies are suggested in *Figure 8*.

Wind Technology Status and Initiative Targets

As illustrated in Figure 9:

- Wind energy costs are presently in the range of 7-10¢/kWh. Existing windfarm layouts were done largely with limited understanding of critical machine siting parameters, using economic criteria driven by now-expired tax considerations.
- As a result of product development programs such as the PG&E/EPRI/U.S. Windpower Advanced Wind Turbine Project, and follow-on demonstration efforts, a more robust portfolio of high quality wind machines will become available. Developmental work in progress to scale up wind machine size and optimize designs will result in 30% reduction in turbine costs to less than $750/kW. This is a critical need, considering the capital-intensive nature of wind power plants.
- Improved machines, coupled with better understanding of machine siting parameters will reduce wind energy costs to 5-7¢/kWh (with at least 2000 MW in Northern California).

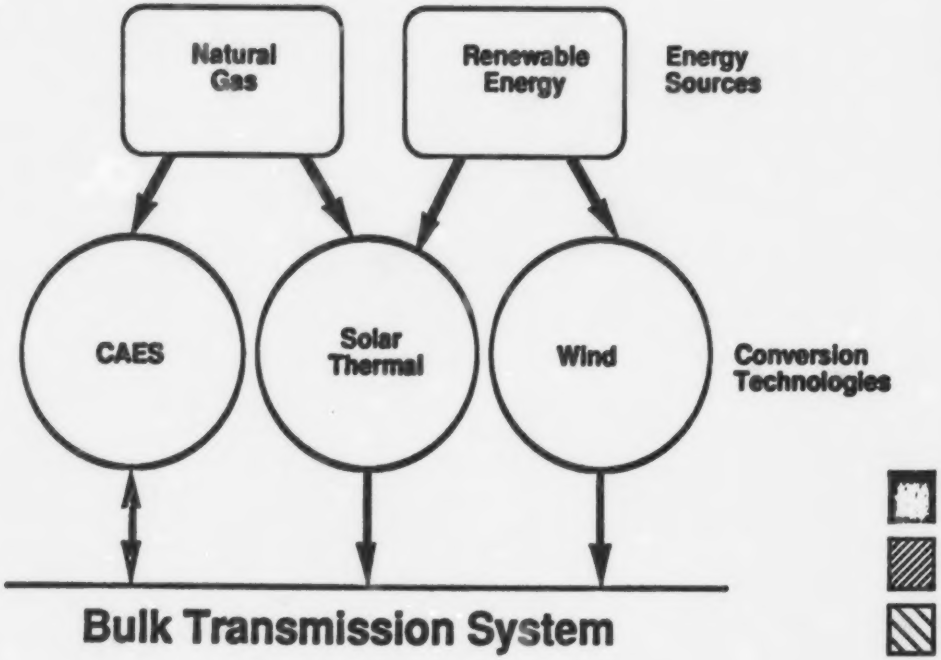
V. Wind Energy and Electric Utilities

Having provided a general sense of how wind energy fits into one electric utility's resource strategy, it is appropriate to identify the issues electric utilities will be dealing with as they make decisions regarding wind.

The issues will initially be dealt with in the following order and then with increasing sophistication over time, if the initial answers are positive.

1. Is there a developable resource within the service area and how large is it?
2. Given the quality of the indigenous resource and its match to system load, is there hope for economical production?
3. Is viable technology available, and are existing wind equipment vendors financially stable and technically capable?
4. To what extent are improvements in current technology possible and likely?
5. What is the capability of transmission links between prime resource areas and load centers?
6. How does wind strategically fit into the utility's generation mix and business environment?

Renewable Central Utility Expansion



Natural Gas

Renewable Energy

Energy Sources

CAES

Solar Thermal

Wind

Conversion Technologies

Bulk Transmission System

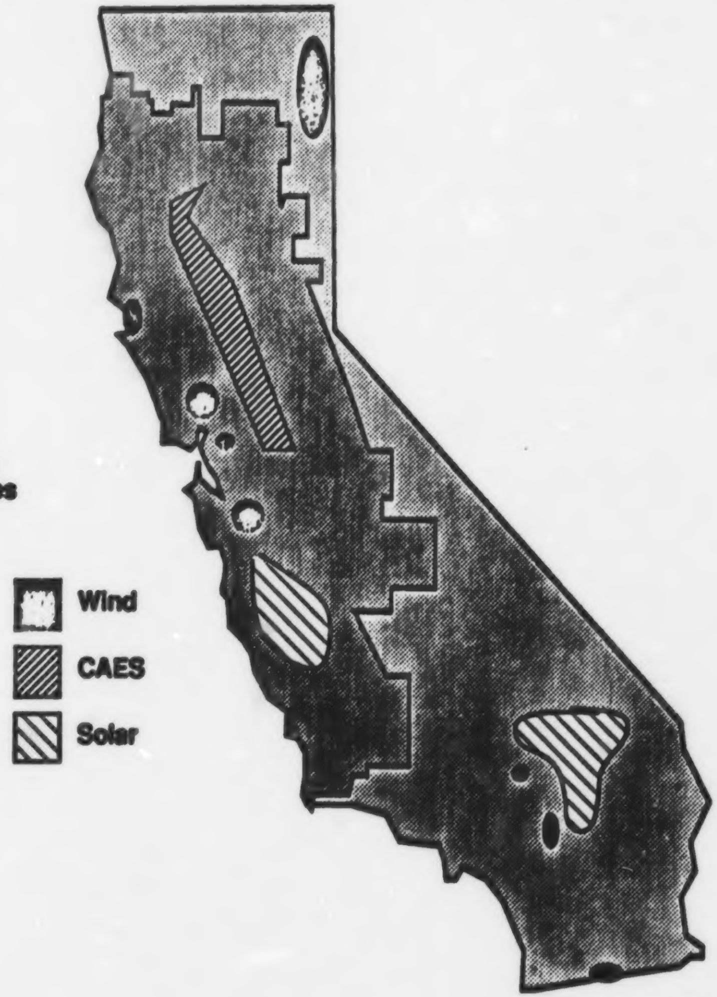
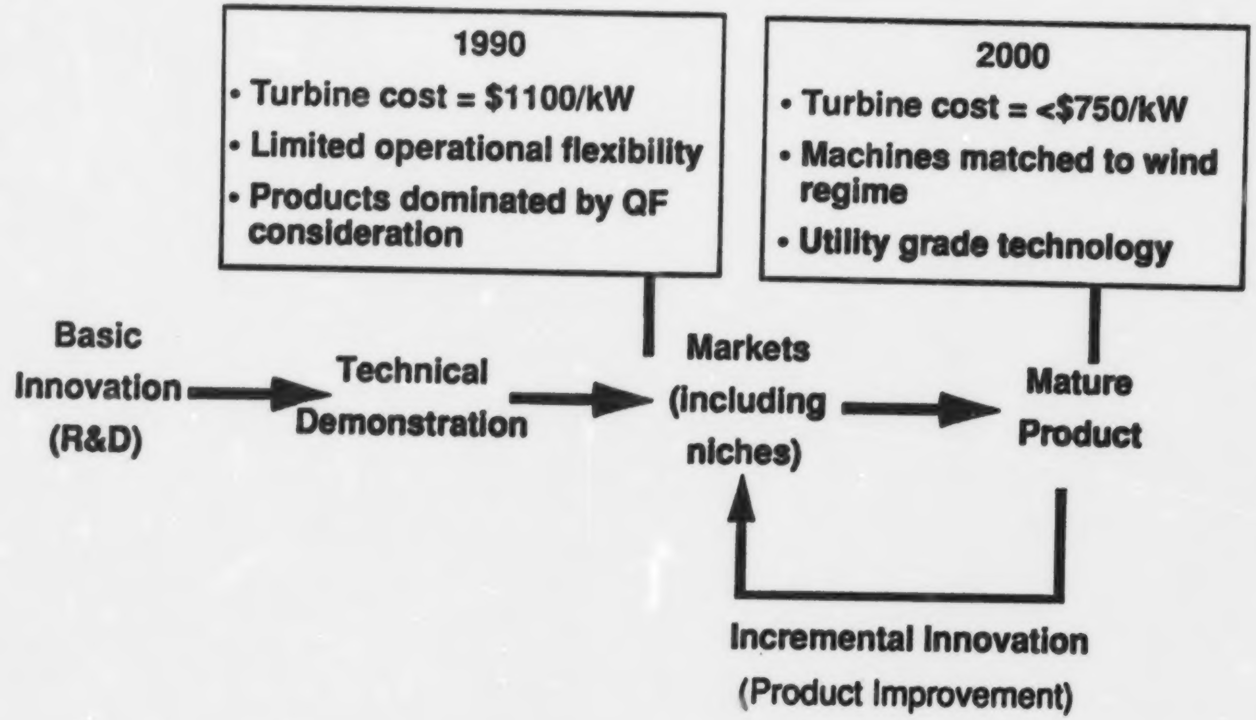


Figure 8

Technology Status and Initiative Targets

Wind



1990
- Turbine cost = $1100/kW
- Limited operational flexibility
- Products dominated by QF consideration

2000
- Turbine cost = <$750/kW
- Machines matched to wind regime
- Utility grade technology

Basic Innovation (R&D)

Technical Demonstration

Markets (including niches)

Mature Product

Incremental Innovation (Product Improvement)

91-1-11

Figure 9

7. How will the evolution of the national and worldwide wind industry and market evolve and what impact will this have on wind cost?

Resource Issues

Proper and accurate estimates of resource potential are difficult. It has been 15 years since utilities in California began to develop and analyze wind resource information, and there is still a factor of two or three uncertainty in estimates of ultimate development potential. For PG&E the range of uncertainty is between 2000 MW and 5000 MW.

The four stages of resource assessment are: 1) to acquire a general understanding of the regional meteorology to identify wind "hot spots," 2) to pass these areas through successive screens to eliminate areas where development is precluded by environmental, land use, or transmission considerations, 3) to conduct properly designed long term measurement campaigns to characterize the resource in each promising area, and 4) to use this data to develop models of the siting areas to support micro-siting decisions. Needless to say this is expensive, and even in California wind resource assessment is incomplete, according to this protocol.

We have learned two things in this process:

1. Accurate, properly designed measurements are extremely valuable, if they are available in time to support decisions. A lot of money is wasted when decisions have to be made without the information.

2. A proper understanding of technological capabilities and micro-siting considerations, e.g., array effects, is necessary to estimate the potential of specific sites. For example, the energy productivity of our Altamont resource could probably be doubled or tripled, based on optimal deployment of emerging machine designs. Siting areas that are not economically developable with current technology may be with future technology.

Cost Issues

It makes a world of difference to a utility whether it perceives a particular option as economically preferred, economically marginal, or uneconomic. Note the emphasis on the word "perceives". Most utilities in the U.S. and probably also Europe perceive wind power as uneconomic and likely to remain so, at least in the context of their own wind resource. These perceptions are largely based on five to ten year old information, and in that framework, they are entirely correct. Some utilities are beginning to realize that current wind technology applied to high quality resources brings the wind option into the "economically marginal" range. Few utilities are yet aware that technology could be available within five years or so that will make wind an "economically preferred" option, even without significant internalization of the environmental and social costs of non-renewable options. Thanks to the active market for wind power in California, the major California utilities are now convinced of wind's economic superiority. Accordingly, they are now proposing wind as their first choice, along with natural gas power plant repowering, for future system expansion to meet load growth.

Technology Issues

Technology issues are difficult to separate from cost issues. Perhaps the important distinction is that cost trends discussed above are driven by scaling up and otherwise reducing the installed costs of the wind turbines, while at the same time improving energy capture. By contrast, most technology deficiencies and problems manifest themselves in low availabilities, expensive corrective maintenance, and high operating and maintenance costs overall.

As I will report in a separate paper, one must look beyond the average technical performance of the more than 15,000 turbines operating in California. The most reliable, highest availability, and best performing machines have operation and maintenance costs in the range $0.01-0.15/kWh, even though they are not expensive machines on the basis of installed cost. Installed costs of these machines are now in the range of $1000/kW. Good technical characteristics can be achieved through costly overdesign, or through incremental improvement of less material intensive designs based on accumulated field experience.

Technology Opportunities

Wind economics are driven in part by energy capture, and this can be improved by variable speed operation, which allows the real time optimization of aerodynamic efficiency. Variable speed operation can be achieved by electronically decoupling generator and line frequencies, thus allowing the rotor speed to be tuned to wind speed. Modern power electronics devices now have the current and voltage capabilities to meet the requirements of the necessary power conversion systems.

As illustrated in Figure 10, variable speed operation provides a comparably important benefit to overall cost reduction, by buffering the turbine drive train from the variations in torque that accompany operation in gusty or turbulent wind conditions. Resulting reductions in fatigue loadings can permit lighter, lower cost, longer life, and lower maintenance structural and rotating components.

Significantly to utilities, the electronic conversion component can, as an artifact of its function, also permit real time adjustment in power factor, such that a wind power plant can have the same reactive power supply capability that conventional utility power plants traditionally provide. Likewise the quality of power from the generation source is high, in terms of harmonic content, frequency operating band, and other figures of merit.

Transmission Issues

Interconnection of a wind power plant with the utility grid can be a major economic driver, and, in some cases it may require transmission routings that are aesthetically or environmentally unacceptable. Wind development in northern California has been facilitated by the fortuitous proximity of the Altamont Pass area to a particularly strong area of the PG&E transmission system. The Tehachepi area in Southern California represents a much less fortuitous match.

The Tehachepi case is instructive, because it motivated the use of a relatively new technology that permits dynamic rating of transmission lines. Current carrying capabilities of transmission lines are conventionally determined by the need to limit conductor temperature and thus avoid accelerated damage to the line. Conservative assumptions regarding ambient conditions are used. Traditional design criteria do not account for the fact that when the wind power plant is generating, the wind speed is also increasing the rate of convective heat transfer from the line to the ambient air. Using "power donuts" and other sensors, line temperature can be measured, and more wind power can be transmitted than the static ratings would allow. This technique can avoid costly line upgrades, which might otherwise economically limit the extent of resource development in constrained areas.

Strategic Issues

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Effect of Power Electronic Converter

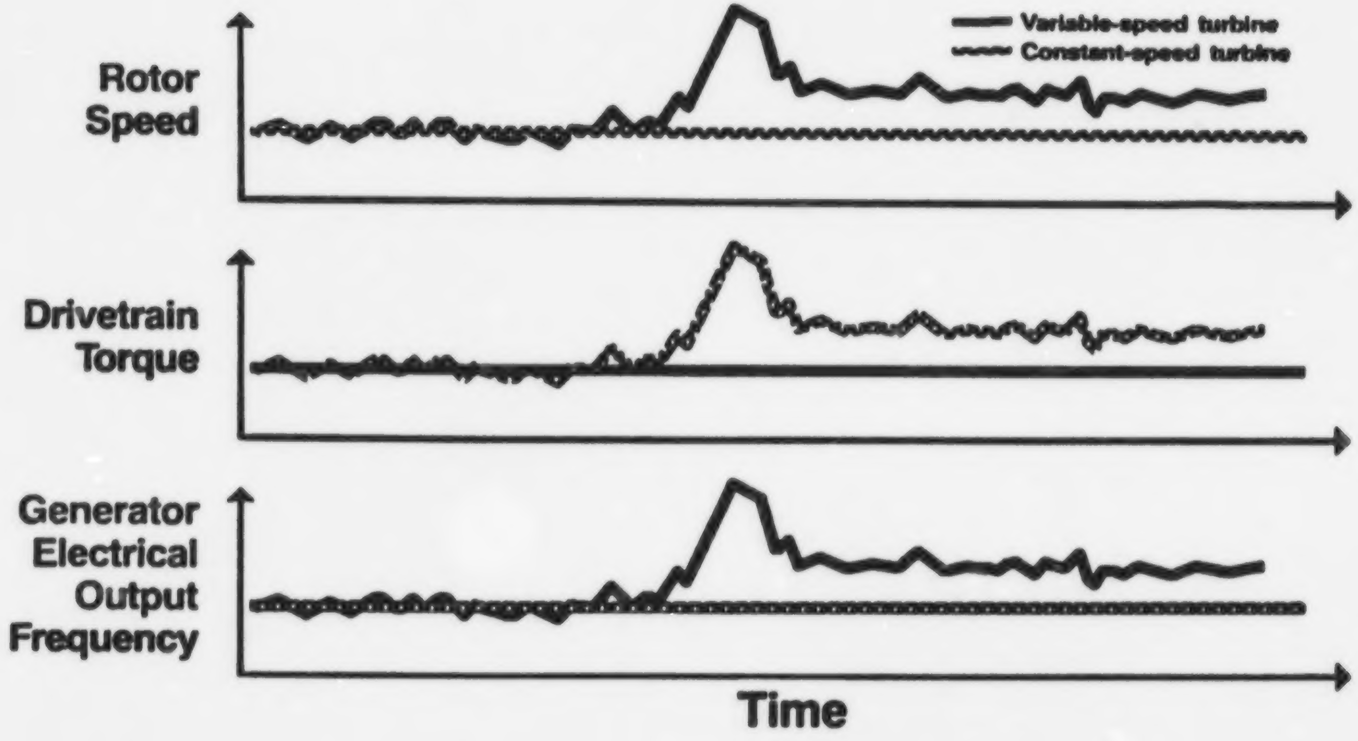

Figure 10

As noted above, utilities will deal with wind differently, depending on how they perceive its economic competitiveness in their region. Companies that perceive wind as economically preferred will build it into their overall resource strategy and take steps to become as knowledgeable about it as possible based on direct experience. Their initiatives will include demonstration windfarms to evaluate advanced concepts and hardware, and their analysis efforts will seek to more accurately assess the energy delivery potential of economically developable resources.

The integration of wind into PG&E's resource strategy is discussed in the first part of this paper. In support of the strategy, we have an on-going cooperative R&D initiative with U.S. Windpower and EPRI to develop an advanced variable speed wind turbine. In addition, our plans include a PG&E hosted advanced wind farm demo that will be fully coordinated with the U.S. D.O.E. advanced wind turbine program.

Since wind will be a least cost energy supply option for PG&E, we want to accelerate the introduction of advanced technology, because this will maximize the percentage of our system energy needs that are supplied by wind. In 1990 the percentage was 1.3%, or roughly 1 billion kWh, as illustrated in Figure 11.

Utilities that see wind as economically marginal will probably respond in a variety of ways depending on the pressure they feel to be perceived as supportive of renewables. From our experience, the most appropriate response would be to invest in resource assessment. In the future, wind economics will be far more sensitive to the quality and location of resources than on the costs of turbines.

Utilities that perceive wind as uneconomic will be well advised to up-date their perceptions periodically.

VI. Market and Industry Development

Based on recent resource estimates and the emerging favorable economics of wind, the U.S. market for windpower will be large, probably dwarfing the current California market. For example, additional resources accessible to our western U.S. regional grid are quite significant. See Figure 12. It will also be a competitive, low cost market dominated by low cost producers. Access to and/or control of premium resources may be more key to market share than superior technology.

The trends in the U.S. electric generation market toward competitive bidding and least cost planning will exert strong downward pressure on costs, while market volume will yield economies of large scale production for leading companies. The U.S. market will be open to overseas suppliers from Europe and Asia, but there will be intense price competition.

European and other world markets may differ substantially from the U.S. in the levels of competition they engage and the technological variations they favor. It is a matter of some interest in the U.S. whether U.S. suppliers will enjoy the same access to European markets as European suppliers now enjoy in the U.S.

VII. Summary and Conclusions

PG&E is in a similar situation to that of many other utilities world-wide. Our system can meet near term needs without expansion. However, we anticipate gradual retirement of existing units combined with significant electric load growth pressures. After careful

1990 Energy Deliveries from Wind Plants in PG&E's Service Territory

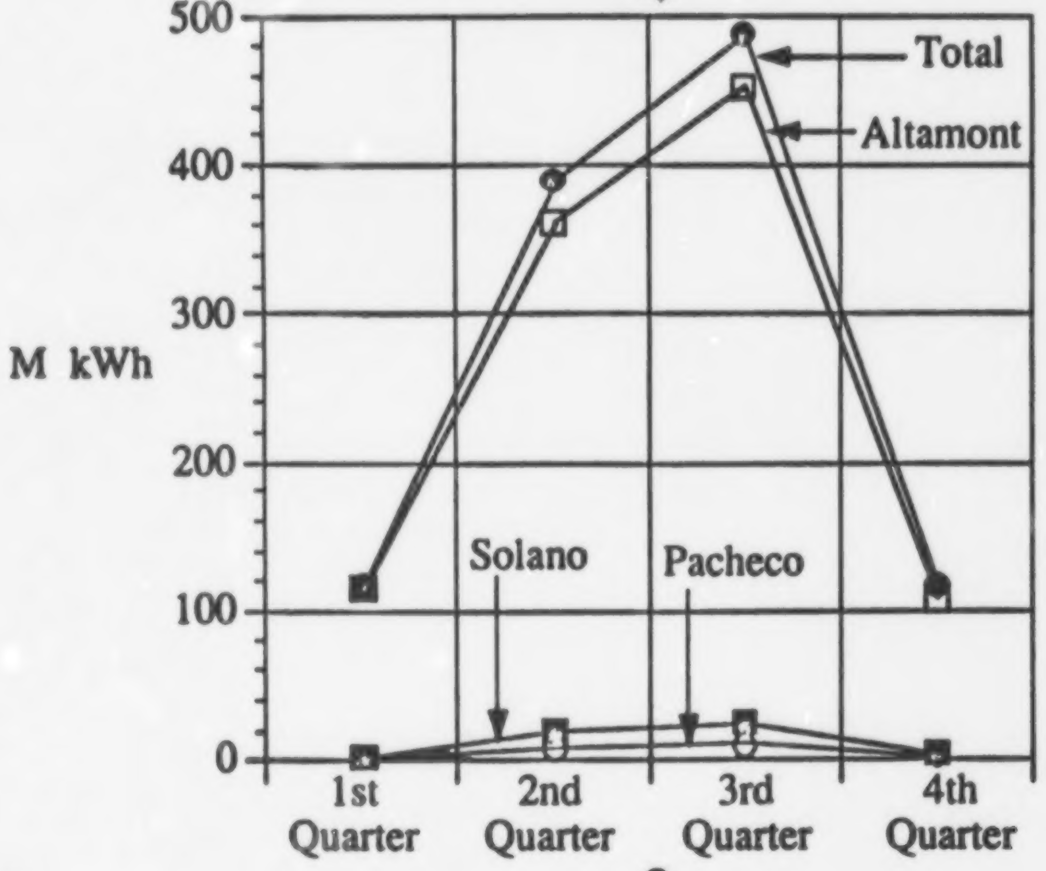

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Figure 11

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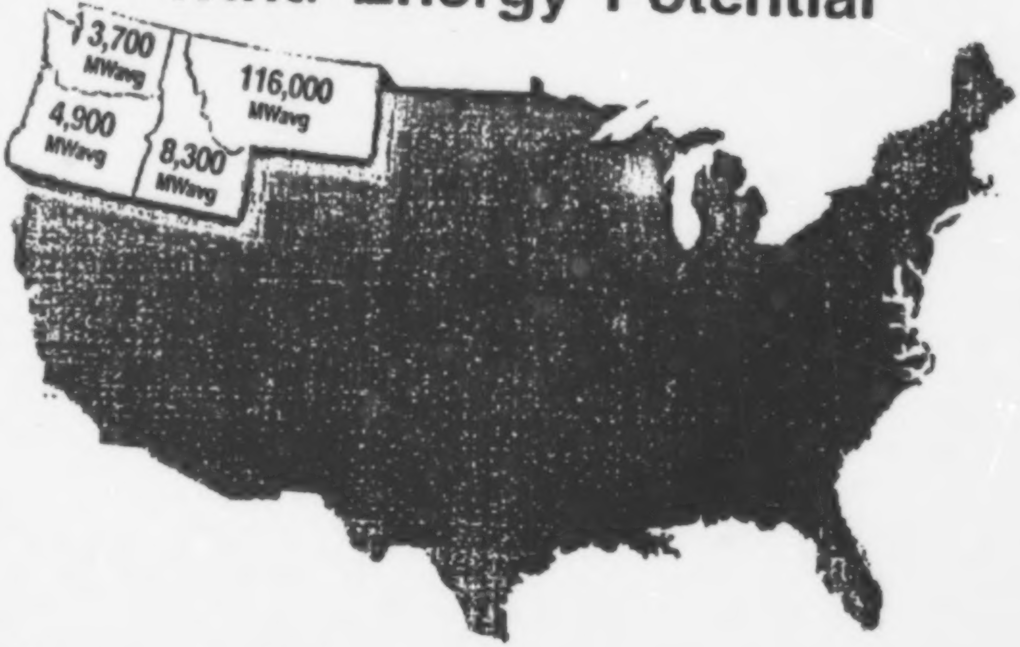
Pacific Northwest
Wind Energy Potential


3,700
MWavg
116,000
MWavg
4,900
MWavg
8,300
MWavg

A recent study by the Pacific Northwest Laboratories for the Department of Energy highlights the immense potential of wind.

Figure 12

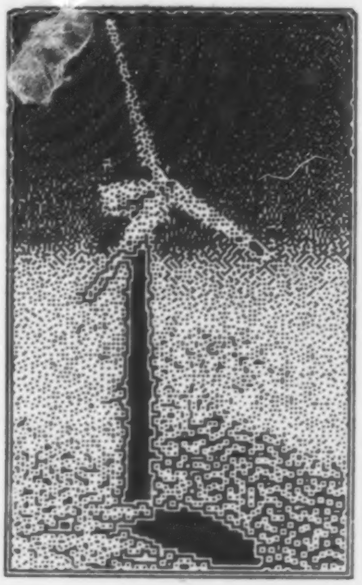
evaluation of available and potential options, it appears that future needs can be met in an environmentally and economically sound manner, provided:

1. **Efficiency.** Investments are directed toward improved efficiency in customer energy use and utility system operation, while an efficiently structured market is established for electric supply.

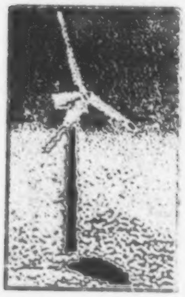
2. **Advanced Natural Gas Conversion.** Technical readiness of ultra-clean, ultra-efficient gas-fueled power plants is accelerated.

3. **Renewables.** Costs of renewable technologies are reduced as rapidly as possible and market opportunities are provided for emergent industries.

We believe this strategy, tailored to address local opportunities and constraints, is widely applicable in developed and developing parts of the world. Moreover, we are convinced that wind power will comprise a major portion of the expanded renewable energy use that will be required. Finally, we are hopeful that our corporate experience may encourage other utilities to seriously and thoughtfully examine their wind resources and opportunities.



THE
SEVENTH ANNUAL
CANADIAN
WIND ENERGY
CONFERENCE '91



WELCOME:

OPENING REMARKS

CanWEA '91

Welcome : Opening Remarks

8:30, Monday morning, Réal Reid, president CanWEA.

First, especially for those that are new to CanWEA, let me introduce the Association : CanWEA was founded in 1984, it is a non profit organization who regroup wind Turbines, manufacturers and suppliers, engineers, research scientists, consultants, utility representatives, wind turbine owners and wind enthusiasts.

Its goals are to promote wind energy as a clean, cost effective way of generating energy,

CanWEA, as well as AWEA and EWEAs have always requested a level playing field, this is why the issue of social costs of electricity generation is so important to CanWEA (and we believe to society as a whole).

CanWEA believe that when all externalities are considered, Wind is very cost effective as an adjunct to other existing energy sources.

CanWEA role is not to ask wether new production facilities are required : but if they are required, we pretend that wind should be seriously considered.

As you will hear in the next two days, during the conference, the potential of Wind is very high in both Canada and the US and Wind Energy technology has progressed so much over the last 10 years that it is competitive in many parts of the world even without externalities. See figure 1: situation on the main grid in Quebec today.

Wind Turbines of up to 500 kW (35-40 m dia) are commercially available with a very good track record, in the 98-99%, and better ones are in development.

Social costs of Electricity Generation

What are social costs:

Social costs could be viewed as the costs that are born by society in general, costs that are not charged directly to the user or to the producer of energy : they could include environmental degradation, increased health care, tax credits, etc... the list is long and I will let the speakers give you more details.

Three methods have been used to calculate the environmental effects of energy consumption:

- **Control cost** would be the amount required to comply with existing environmental factors
- **Damage cost** would ,measure the actual damage to the environment
- **Contingent Evaluation** by which surveys are used to find out how much people are willing to pay to avoid incurring a specific kind of environmental damage or other social cost. Or how much compensation they would ask to be willing to suffer a particular insult to their surroundings.

Use of social costing:

With the push of the Toronto Conference of 1988 at which some countries took the engagement of reducing CO_2 emissions by 20 % by the year 2005, some countries have enacted low level fuel or CO_2 taxes. Others have come up with incentives for clean energy sources, preferred ranking of energy sources, or some form of accounting for externalities in Utility planning processes conservation and process efficiency enhancement efforts.

Effects of Social Costing on Wind Energy:

As table 1, (Ottinger, 1990) shows, the social costs can be significant, often almost doubling the cost of a given energy source.

The result of its implementation would be to change a renewable (by Renewable, CanWEA means **WIND**) project from neutral to very profitable.

One local example is the Magdalen Island project study for a 5 MW Windfarm which with standard costing methodology is about neutral, would it be done ???. But with social costing, table 2, the project would change from neutral to very interesting and would be done!!!

Another local example is : To save water, the rainfall being less predictable than wind, Hydro-Québec will run its Tracy thermal plant for a year as a base load plant (its normal role is as a peaking plant). Social costing says that **Wind Energy** can provide that energy at a lower cost to society!!! (but not at a lower cost to Hydro-Québec using a standard costing methodology, see table 3.

Put another way : Social Costing, by taking into account all costs of energy production would favor the development of more benign energy source for the same or improved quality of life which is (I think) the defenition of Sustainable Growth (UN Brundtlandt Commission)

Enough Said, I will leave the floor to the experts:::

- According to "Environmental Costs of Energy" by Richard Ottinger, report prepared for the New York State Energy Research and Development Authority (NYSERDA) and the U. S. Department of Energy, (1), (2), the environmental costs of electricity generated by:

in CDN ¢/kWh

oil are from 3,1 to 7,7 ¢/kWh

coal are from 2,9 to 6,6 ¢/kWh

waste to energy are 4,6 ¢/kWh

nuclear are 3,3 ¢/kWh

natural gas are from 0,8 to 1,2 ¢/kWh

biomass are from 0,0 to 0,8 ¢/kWh

solar are from 0,0 to 0,5 ¢/kWh

wind are from 0,0 to 0,1 ¢/kWh.

TABLE 1

COUTS SOCIAUX + CARBURANT
CENTRALE DIESEL
ILES DE LA MADELEINE

Hypothèses:

- puissance installée 68,4 MW
- facteur de capacité: 47 %
- carburant:
  - huile lourde
  - densité spécifique 0,98 = 980 g/l
  - teneur en souffre 1,5 %
    - d'où S = 980 x 1,5 % = 14,7 g/l
    - et CH_2 = 980 x 98,5 % = 965,3 g/l
  - coût 4,15 ¢/kWh
  - rendement de la centrale = 5,3 kWh/l
  - formule moyenne du carburant: CH_2
  - 1 $ US = 1,15 $ CDN

Équation stoéchiométrique:

CH_2	$+ S$	$+ 5/2\ O_2$	$+ 9{,}4\ N_2$	$= CO_2$	$+ H_2O$	$+ SO_2$	$+ 9{,}4\ N_2$	$+ NO_x$	+ Mat Part
14	32			44		64		38	(poids mol)
965,3	14,7			3034		29,4		19,6	g/l
182,1	2,77			572,4		5,55		4,5 (1)	0,65 g/kWh

Coûts

Polluant	$ US/lb (2)	¢ CDN/g	g polluant / kWh	¢ CDN/kWh
CO_2	0,0068	0,0017	572,4	0,99
SO_2	2,03	0,515	5,55	2,86
NO_x	0,82	0,208	4,5	0,94
Mat Part	1,19	0,302	0,65	0,20
		Total, coûts sociaux		4,99
		+ coût du carburant		4,15
		Total		9,14 ¢/kWh

TABLE 2

COUTS SOCIAUX + CARBURANT
CENTRALE THERMIQUE
TRACY

Hypothèses:

- puissance installée 600 MW
- facteur de capacité: 65 %
- carburant:
  - huile lourde
  - densité spécifique 0,98 = 980 g/l
  - teneur en souffre 1,5 %
    d'où S = 980 x 1,5 % = 14,7 g/l
    et CH_2 = 980 x 98,5 % = 965,3 g/l
  - coût 2,6 ¢/kWh (@18 $/bbl:
    rendement de la centrale = 4,35 kWh/l)
  - formule moyenne CH_2
  - 1 $ US = 1,15 $ CDN

Équation stoéchiométrique:

$$CH_2 + S + 5/2\ O_2 + 9{,}4\ N_2 = CO_2 + H_2O + SO_2 + 9{,}4\ N_2 + NO_x + \text{Mat Part}$$

14	32	44	64	38	(poids mol)
965,3	14,7	3034	29,4	19,6	g/l
221,9	3,38	697,5	6,76	4,5 (1) 0,65	g/kWh

Coûts

Polluant	$ US/lb (2)	¢ CDN/g	g polluant / kWh	¢ CDN/kWh
CO_2	0,0068	0,0017	697,5	1,20
SO_2	2,03	0,515	6,76	3,48
NO_x	0,82	0,208	4,5	0,94
Mat Part	1,19	0,302	0,65	0,20
		Total, coûts sociaux		5,82
		+ coût du carburant		2,6
		Total		8,4 ¢/kWh

TABLE 3

STATE OF THE ART

International Trends...

Significant increase in budgets for R&D.

Increased number of countries where wind energy becomes a competitive source of energy

Most wind energy projects are of the grid-connected wind farms types

Increasing size of wind turbines.

Growing collaboration between industries and utilities

Growing interest and first demonstration of offshore wind farms

International Trends

The newcomers to the wind energy scene are more interested in wind potential

The "oldtimers" to the wind energy scene feel more interest towards technical development of the technology.

Growing interest for national development of wind industry.

A growing recognition of the rationale and the needs to include social (or external) costs for representing the real cost of electricity production technologies give wind energy a net advantage.

Growing number of international collaboration projects in wind energy.

Wind Potential...

Estimated world potential: 10 000 GW

North-American potential: 2 360 GW

European potential: 2290 GW.

In year 2020, 450 GW wind capacity will be operational over the world.Their average energy output will be 900 TWh annually.

At the moment, the economical wind energy potential of the Pacific-North-West zone is 18 000 MW

In Germany, there will be 1000 MW of wind capacity installed in 2005.

Wind Potential

Northern California possesses a wind energy potential of 5000 MW with an average production cost lower than 12¢/kWh.

In Greece, a wind energy potential of 1200 MW will provide 10% of the annual energy consumption.

Canada possesses a wind energy potential of 4 500 MW that can be easily tapped over the next 25 years.

Technology

High growth of the wind energy industry

High equipment reliability .

Trend towards large diameter grid-connected machines:

- Strong competition among producers of machines of 25-28 m diameter (225-300 kW)
- Rotors of 33 and 35 m diameter (400 - 500 kW) commercially available.
- Rotors of 40 m (600-750 kW): in the pre-commercial stage.

Intensification of R&D Activities

Wind Resource Evaluation

Aerodynamics: Single Machines/Wind Farms

Electrical Conversion & Machines

Regulation & Control Systems

Materials

Variable Speed/Variable Pitch

Wind/Diesel

Modelisation

Legal & Environmental Aspects of Wind Projects

Costs...

The **cost of wind energy** has reduced from 14 to 5 ¢/kWh from 1982 à 1990.

Ex: In Denmark, today, wind energy is competitive with energy produced by conventional sources (4¢/kWh at 8.5 m/s; 8¢/kWh at 6.5 m/s).

Cost/kW:
$1900 US/kW in 1985; $1000 in 1991.

Introduction of the concept of **social (external) costs** : the real costs of energy production technologies to society.

By not considering these costs, serious distortion of market forces in energy production technologies are maintained.

Costs

Competitiveness of wind energy costs (not including social costs) relative to coal and nuclear: 4.7 to 7¢ US/kWh

The highest number of permanent jobs per installed kW belongs to wind technology (Operation and Maintenance)

R&D budgets increase:

in Europe: 150 M$ annually

in USA, 21 M$ for 1992 (doubled relative to 1991)

in Sweden: 42 M$ for the next 5 years.

Wind projects today...

Wind projects today generally mean hundreds of machines (25-40 m dia.). They are projects of typically 100 MW.

- US

In California:>17 000 wind turbines
> 1600 MW installed capacity,
> 1 % of the electrical demand in 1990.
2.7 TWh were produced in 1990
(+- San Francisco annual consumption)
- in 1987, Altamont Pass wind farms load carrying capacity was 140 MW

Pacific Gas & Electric (PG&E), Niagara Mohawk and EPRI are partners with US WindPower in the development (20 Million US$ invested) of a 400 kW wind turbine. An advisory committee to which about 50 North-American utility companies are participating has been formed to follow this project.

Wind projects today

- Denmark

3 000 machines installed
360 MW of installed power,
2,5 % of the electrical demand in 1990
plans for 10 % in 2000
- Reliability has reached 99.2 % in 1989 -
Cost of energy has decreased from 20 to
5,3 ¢/kWh between 1980 and 1990

A 5 MW wind farm has been erected and commissionned in July 1991 offshore from the cost of Denmark. The 11 Bonus wind machines of 450 kW were erected in 10 days (10);

- Holland:

50 MW wind capacity to be installed in 91; 130 MW planned for the end of 1992

Projects under study...

- •Germany: growth of 50 MW wind capacity per year for the next 4 years.

- Sweden has decided to close all of its nuclear power plants starting in 1995; It is expected that the energy deficit beprovided by 15 000 wind machines that would produce 6 TWH of energy annually (3,4)

- •US WindPower proposes a 100 MW wind farm in the Solano county, California, to replace the Rancho Seco nuclear plant, closed last year after a public referendum.(6)

Projects under study

- US: "Pacific Northwest Laboratory" from Battelle (report for the US Department of Energy):
  - The US wind potential is sufficient to meet all of the electrical needs of the US
  - Realistic goal : 20 % of the electrical needs of the US could be provided by wind energy before 20-30 (4,5),

- Canada: study by EMR Canada:
  - 4 500 MW that could be harnessed over the next 25 years. This represents an economic activity of 6 billion $
  - A 9 MW wind farm will be built in Alberta in 1991 (7); Another one of 1.5 MW is also planned for 1991.

Obstacles: Environmental Aspects...

Perception:

Wind energy still perceived as an unreliable and costly energy source.

Open information procedure on the technology is vital before any project implementation.

The public acceptance process can easily last up to two years.

Noise:

The definition of "tolerable"noise represents a major objection in the acceptance process of wind energy projects: new machines are less noisy

Obstacles: Environmental Aspects

Visual and Wildlife Impact:

Many projects have been delayed or even abandoned for these reasons. The selection of sites is very critical.

Existing farms are generally perceived as an added value to the landscape

Smaller groups of machines are preferred.

Land Usage:

Wind farm infrastrustures use 3% of the land area.

As an example, in the Altamont Pass, in California, a local paper mentioned about a local farmer "Tony Souza and his family produce beef and electricity."

WIND ENERGY POTENTIAL

CANADIAN WIND ENERGY TECHNICAL AND MARKET POTENTIAL

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ABSTRACT

This paper summarizes the contents of a report, now in publication, which has the same title as above. It describes a recent study to review the current status of wind energy technology, to estimate the size of its technical potential in Canada, and to assess its economic market potential under several scenarios over about the next 25 years. The technical potential is large, with applications to water pumping on farms, the coupling of wind turbines to diesel-electric systems in remote communities where fuel costs are high, and the supply of electricity to the main power grids. The main-grid application has much the greatest technical potential, but it cannot be economically exploited under the present utility buy-back rate structure for intermittent power sources. A change in government policy toward market development of renewable energy sources, such as is already taking place in several European countries, would greatly increase market potential, decrease CO_2 and SO_2 emissions and benefit the Canadian wind energy industry.

1. INTRODUCTION

An Energy, Mines and Resources (EMR) Canada report, titled "Canadian Wind Energy Technical and Market Potential", is to be published shortly, in which the technical potential for wind energy development in Canada is estimated, as well as the economic market potential over about the next 25 years. The present paper gives a brief summary of its results, but no attempt is made to give a complete description of the methodology that was used. It should be stated, however, that many assumptions were made, and the quantitative estimates of potential are therefore approximate.

2. TECHNOLOGY STATUS

Wind turbine technology has reached a mature status during the past decade. About 2000 MW of wind power capacity are installed worldwide, most of it in California where wind supplies somewhat more than 1% of that State's electricity. In Europe several countries have set targets for installed capacity between 300 and 1000 MW by year 2000. Annual R&D expenditures continue to increase in the IEA countries, although Canada's contribution is small.

Experience in California and elsewhere has shown that wind turbine availability (percent of the time a wind turbine is available for operation) has reached about 95%, comparable with that of other power plants. Similar reliability has been achieved in a few Canadian turbines since about the mid-1980s.

There have been corresponding improvements in wind plant capital cost. Installed turbine costs have been roughly halved since 1980, but now appear to be levelling off. In the EMR study a level "turnkey" cost of $1100 (in 1988 Canadian dollars) per kW of rated power was assumed beyond 1995 in the basic scenario of the market analysis. Two recent Canadian VAWT designs suggest that installed costs as low as $700 per kW may be possible, but these are not yet in production. In one of the market scenarios of the study, the effect of a one-third capital cost reduction was investigated.

Operating and maintenance (O&M) costs in the study have been taken to be 1 ¢/kWh for turbines connected to the main grids, but twice as much in remote communities. Allowance has also been made for one major component replacement (such as rotor blades) during the 25 year turbine life.

3. WIND ENERGY APPLICATIONS AND TECHNICAL POTENTIAL

The technical potential for wind energy (irrespective of economic limitations) is difficult to quantify in a country as large as Canada. Average wind speeds are not uniformly distributed across Canada; the windiest regions are near the coasts, in parts of the North, and in the southern prairies. The theoretical size of the resource is enormous; for example, if the windiest one percent of the land area below 60 degrees latitude were occupied with windfarms at acceptable turbine spacing, they would produce about 60 percent of the present total national electricity consumption. Obviously, the practical technical potential must be estimated from other considerations.

3.1 Farm Water Pumpers

There are at present over 800 mechanical water pumping wind systems installed on prairie farms, and they are an economical means of providing water for stock or irrigation in locations too far from the nearest grid to justify the laying of an expensive electric line for motorized pumps. In the EMR study it is estimated that there is a potential for about 40,000 wind pumpers on Canadian farms. Typically a complete system may cost $5,000 to $10,000, and this represents an attractive potential market.

3.2 Small Wind Energy Conversion Systems

Commercial wind turbines rated at less than about 20 kW (about 10 m diameter) are sometimes used in battery-charging applications in remote locations such as cottages, microwave relay stations, etc. While the potential market for these small machines is attractive, the total energy requirement is likely to remain comparatively small, and it has not been estimated in the EMR study.

3.3 Power Production for Remote Communities

There are nearly 400 communities in Canada that are supplied with electricity from large or small diesel-electric generating plants.

About 170 of these, with about 90,000 population, lie in regions where the average wind speed is high enough that wind energy may economically replace part of the high-cost diesel fuel consumption.

As the installed wind power capacity is increased at a given location, the amount of intermittent wind energy that can be absorbed by the system does not increase indefinitely. This is because periods of good winds will often coincide with low power demand. The statistical method of analysis used in the EMR study indicated that if the total installed wind power exceeded the average community power demand, so much energy had to be dumped (or not generated) that the curve of energy absorbed became relatively flat. Although somewhat arbitrary, this level of penetration was taken as the basis for the estimate of technical potential, which is about 175 MW of installed wind power, producing an absorbed annual energy of about 250 GWh. This is about 17% of the present electricity consumption of these communities. As will be seen, however, the economic market is somewhat smaller.

3.4 Power Production in Utility Grids

This application has by far the largest technical potential for wind energy development in Canada. However, unlike the remote communities which have relatively high diesel generating costs, the main utility grids provide comparatively low-cost electricity. It was therefore assumed that acceptable penetration by wind energy would be limited to a level that would require little or no "dumping" of excess wind energy. An analysis similar to that carried out for the remote communities showed that excess energy generation was small if the installed wind power was less than about one-half of the average system power demand. This was taken as the definition of the technical potential for wind power in the main grids. Note that this is one-half of the corresponding criterion for technical potential in the remote communities. Both are somewhat arbitrary, and it must be realized that the resulting estimates, although believed to be rational and probably conservative, are approximate.

Since the electricity consumption in Canada in 1990 was about 486,000 GWh, equivalent to an average power of about 55,500 MW, the above definition yields an estimated wind power technical potential of 27,750 MW. If installed in reasonably windy regions, high-performance modern wind turbines of this total capacity would generate about 52,700 GWh of electricity per year, or about 11% of present total consumption.

4. EXPECTED MARKET PENETRATION IN CANADA

4.1 Methodology

The economic market (as distinct from the technical potential) for wind-electric generation in Canada was estimated separately for the remote communities and for the main utility grid systems. Among other possible criteria, a simple internal rate of return calculation, based upon estimated capital and O&M costs and assumed utility power purchase rates, was used to judge economic attractiveness.

It is important to note that the model simulates only a "business development" market, in which individual turbines or large wind farms are privately owned and operated with the co-operation and approval of the power utility, and not the alternative market for utility-owned wind plants. The latter would involve different assumptions regarding generation costs, acceptable rates of return, etc., and should be assessed more appropriately by the utilities.

In 1991 the purchase rates for intermittent energy sources connected to the main grids ranged from zero (in two provinces) to 4.6 ¢/kWH in Alberta and 6 ¢/kWh in Prince Edward Island. The rates are higher in the remote communities, up to 21 ¢/kWh in the Northwest Territories. These rates, together with the costs mentioned in Section 2, defined the base case "business-as-usual" scenario (called Scenario 1). The calculated internal rate of return was high in remote regions, especially those with high winds in NWT, but negative or near zero for all the provincial utility grids, in Scenario 1.

Following the innovations theory of marketing, two filtering functions were applied to the calculated rate of return to estimate how a traditional market sector adopts new products. Each varies from zero to 100%. The first, plotted in Figure 1, is a function only of the internal rate of return, and shows the assumed percentage of the market that will purchase a new product during its first complete lifetime cycle. Note that acceptance is assumed to be small unless the rate of return is about 15% or more. The second, plotted in Figure 2, is a diffusion function that allows a finite time for the market to develop and for a new industry to grow over the product life cycle (assumed to be 25 years).

4.2 Market Estimate

The estimated market potential (cumulative) by year 2014 is summarized in Table 1. Total rated wind power capacity, capital cost (in 1990 dollars) and the annual wind energy produced by the end of the period are listed. More detail by year and region is given in the EMR study report. Three market scenarios (with variations on the third) were considered, representing different levels of cost and buy-back rates.

Scenario 1 included the costs summarized in Section 2 and current buy-back rates. In this scenario the purchase rates in the remote communities are already high enough that the estimated cumulative market by year 2014 is 81 MW of installed wind capacity, a little more than half the estimated technical potential. It represents a total capital investment of $130 million 1990 dollars. On the other hand the market potential in the main utility grids (105 MW) is less than 0.4% of the estimated technical potential.

In Scenario 2 the regional power purchase rates and all performance parameters remained unchanged, but the wind plant installed capital cost was reduced by one-third. This represents projected cost reduction of new Canadian Darrieus designs that have not yet been put into production, and also allows for possible (but unknown) technical breakthroughs elsewhere. With this cost reduction, the market potential in the remote communities increased by about 50% and was approximately doubled in the main-grid application.

Scenario 3 was designed to show the sensitivity of the main-grid market to variations in power purchase rates, with wind turbine capital and operating costs remaining the same as in Scenario 1. Several factors, not generally taken into account in Canada, could justify increased rates. These include recognition of capacity credit (estimated in Europe to be 20% to 30% of wind plant installed capacity), and concern for the environmental costs of conventional energy generation. No attempt was made in the present study to quantify these factors, but the sensitivity of the market to the value of the purchase rate was estimated by choosing 5, 7 and 9 cents/kWh as alternative rates (in the main grids only). The results in Table 1 show that the sensitivity is extreme: at the 5-cent purchase rate the estimated installed wind capacity by year 2014 is only 175 MW but increases to 1,329 MW and to 5,651 MW for rates of 7 ¢/kWh and 9 ¢/kWh respectively. The corresponding annual wind energy produced at the end of the period amounts to about 0.1%, 0.7% and 3% of present Canadian electricity consumption at the three purchase rate levels. At the mid-level rate (7 ¢/kWh), the estimated market pepresents a capital investment over $2 billion (in 1990 dollars).

5. CONCLUSION

Wind turbine technology reached a mature status during the 1980s, and the technical potential for its application in Canada is large - of the order of 11 percent of national electricity consumption. However, its economic viability is small at present, except for certain applications such as wind/diesel hybrid power plants in remote communities where fuel costs are high, and water pumpers for farms.

The largest potential application is the supply of wind energy to the main electricity grids by extensive wind farms such as those in California and Europe. In Canada this market is severely limited by the low utility purchase rates offered for energy from intermittent power sources, varying from zero to 6 ¢/kWh in different regions of Canada. However, the market appears to be extremely sensitive to possible variations in these rates. When a hypothetical uniform rate of 7 ¢/kWh is assumed, the potential market is about 1,330 MW of installed wind power in the utility grids, capable of supplying about 0.7% of total national electricity consumption, and representing an investment of about $ 2 billion. At 9 ¢/kWh the estimated market jumps to about 5,600 MW, which could supply aboyt 3% of present consumption.

These more favourable purchase rates for wind energy reflect capital cost allowance for some capacity credit and savings in environmental costs. The adoption of favourable rates would appear to require a change in the policies of governments toward market development of renewable energy sources.

6. ACKNOWLEDGEMENT

Many people contributed to the Reference 1 study. Special thanks are due to David Argue of Passmore Associates International, Monique Carpentier, EMR, and Brent Paterson, Alberta Agriculture.

TABLE 1
Cumulative Market Potential to 2014

	REMOTE GRID			MAIN GRID		
	Installed Capacity (MW)	Capital Cost (M$)	Wind Energy (GWh/yr)	Installed Capacity (MW)	Capital Cost (M$)	Wind Energy (GWh/yr)
Scenario 1	81	$130	123	105	$169	232
Scenario 2	121	$145	182	201	$241	447
Scenario 3						
(5¢ rate)	81	$130	123	175	$280	≈460
(7¢ rate)	81	$130	123	1329	$2127	3479
(9¢ rate)	81	$130	123	5651	$9042	≈14800

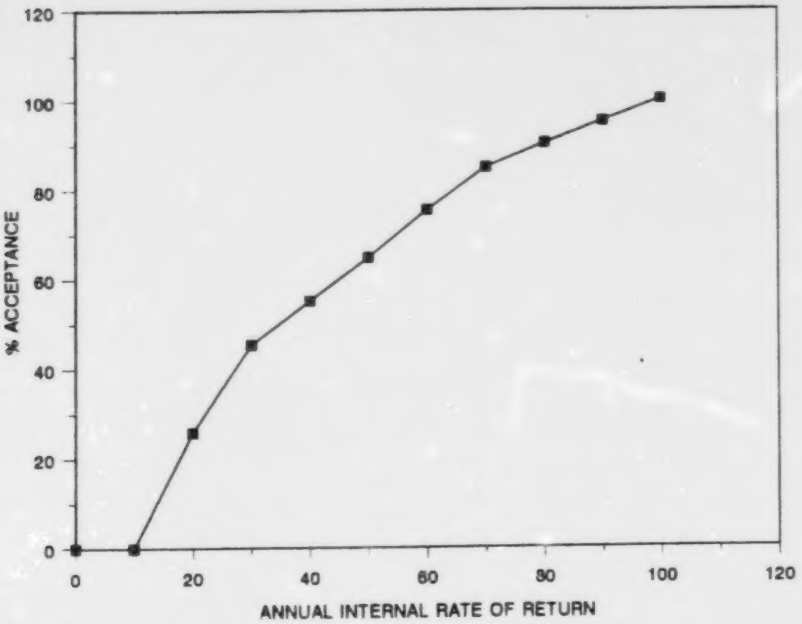


Figure 1: Percent Acceptance vs Internal Rate of Return

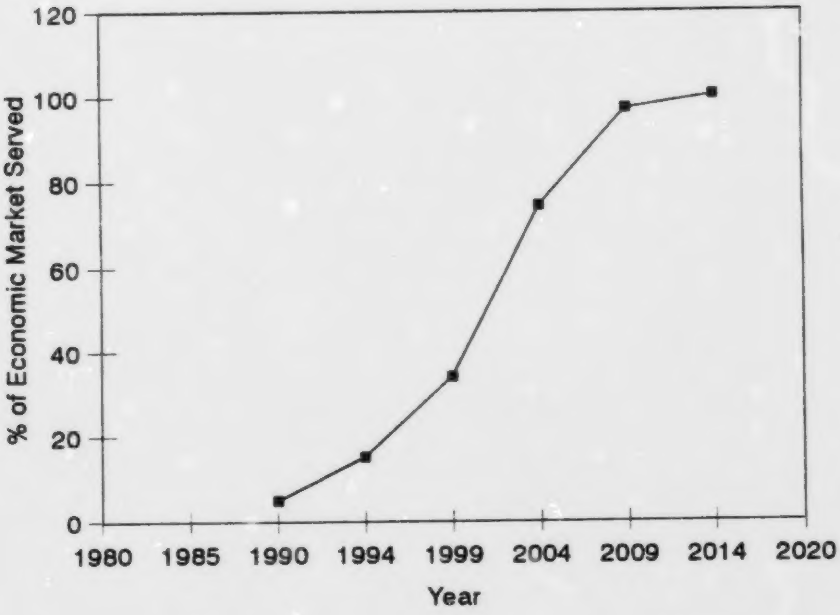


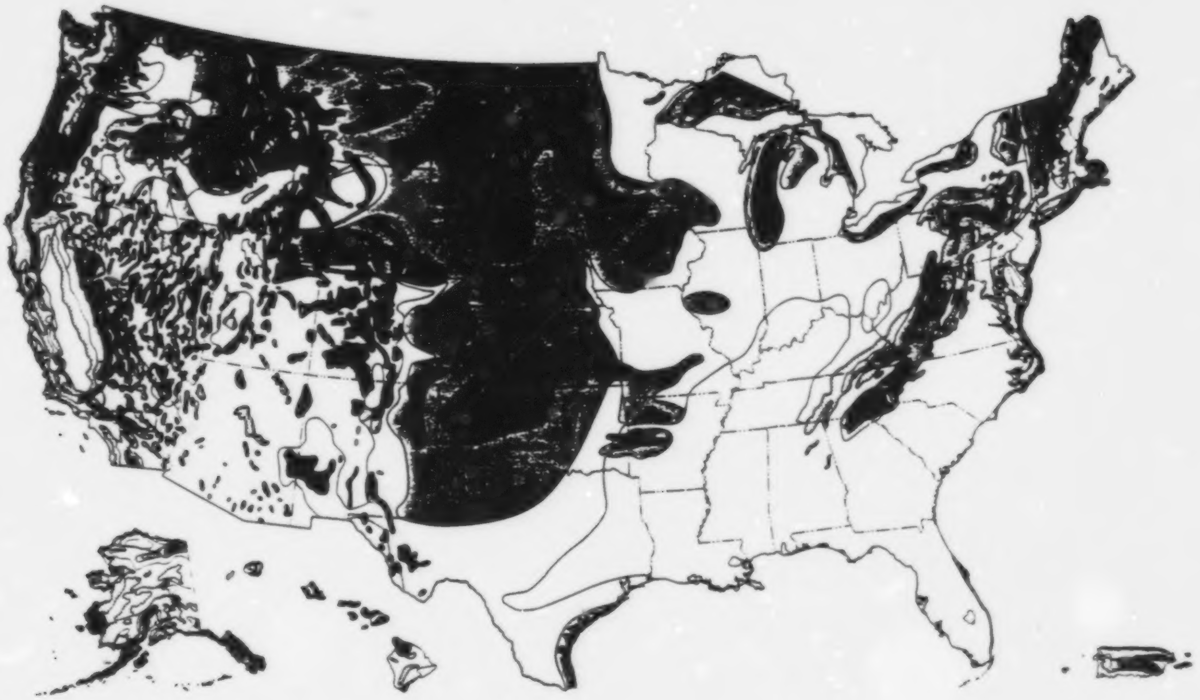
Figure 2: Diffusion Function

Wind Energy Potential in the United States

Dennis L. Elliott

Pacific Northwest Laboratory
Richland, Washington

Wind Energy Resource Atlas



# of the United States

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

Classes of Wind Power Density

Wind Power Class	10 m (33 ft)[a]		30 m (98 ft)[a]		50 m (164 ft)[a]	
	Wind Power Density,W/m²	Speed[b], m/s (mph)	Wind Power Density, W/m²	Speed[b], m/s (mph)	Wind Power Density, W/m²	Speed[b], m/s (mph)
	0	0	0	0	0	0
1						
	100	4.4 (9.8)	160	5.1 (11.4)	200	5.6 (12.5)
2						
	150	5.1 (11.5)	240	5.9 (13.2)	300	6.4 (14.3)
3						
	200	5.6 (12.5)	320	6.5 (14.6)	400	7.0 (15.7)
4						
	250	6.0 (13.4)	400	7.0 (15.7)	500	7.5 (16.8)
5						
	300	6.4 (14.3)	480	7.4 (16.6)	600	8.0 (17.9)
6						
	400	7.0 (15.7)	640	8.2 (18.3)	800	8.8 (19.7)
7						
	1000	9.4 (21.1)	1600	11.0 (24.7)	2000	11.9 (26.6)

---

[a] Vertical extrapolation of wind power density and wind speed are based on the 1/7 power law.

[b] Mean wind speed is estimated assuming a Rayleigh distribution of wind speeds and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution and elevation above sea level.

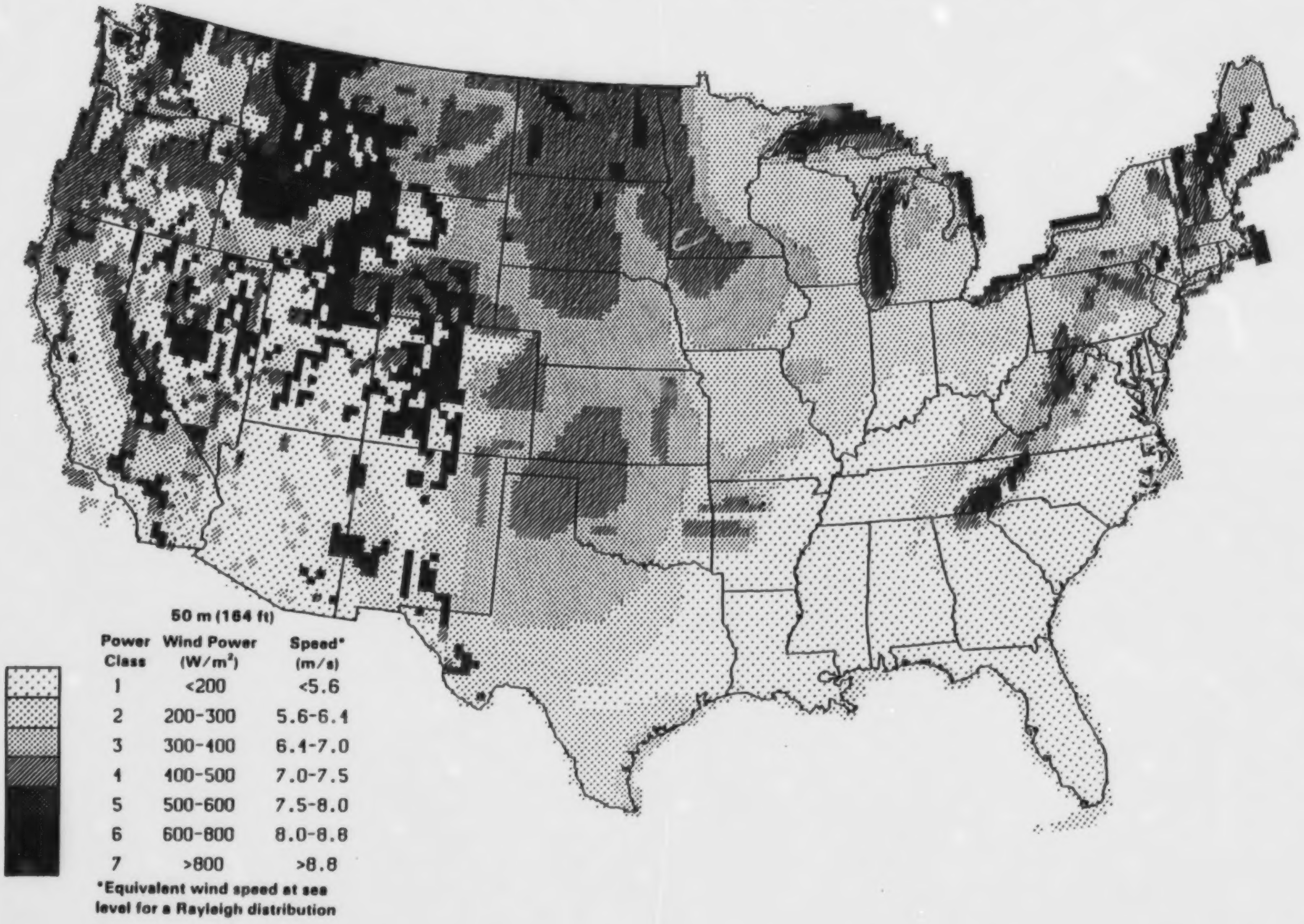
S9106046.2

Comparison of Annual Average Wind Power at Four Sites with Identical Annual Average Wind Speeds at 10 m

Site	Annual Average Wind Speed, m/s (mph)	Annual Average Wind Power Density, W/m²	Wind Power Power Class
Constant Wind Speed (hypothetical)	6.3 (14)	150	2-3
Culebra, Puerto Rico	6.3 (14)	220	4
Tiana Beach, New York	6.3 (14)	285	5
San Gorgonio, California	6.3 (14)	365	6

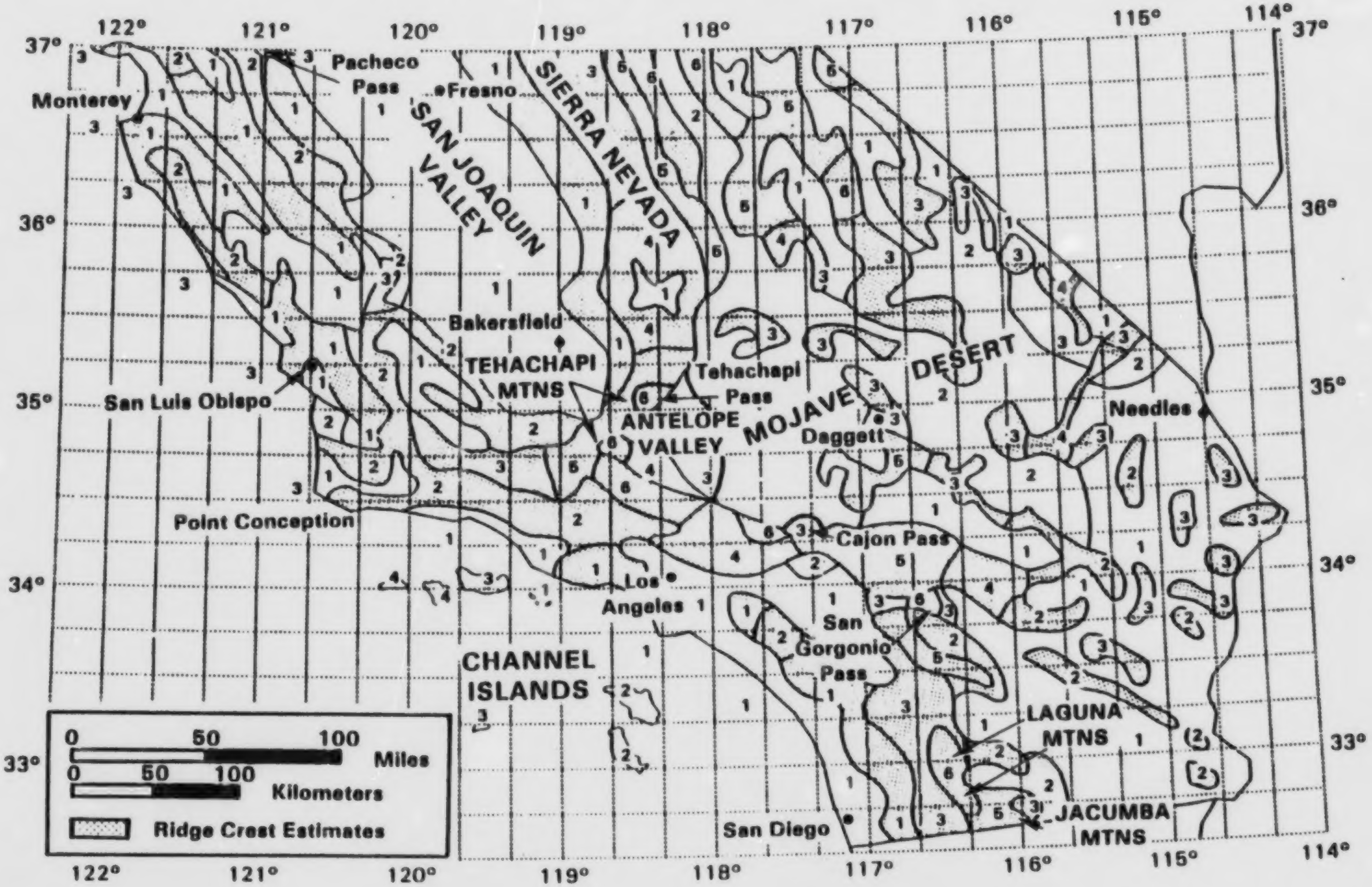
S9106046.5

Annual Average Wind Resource Estimates


50 m (164 ft)
Power Class | Wind Power (W/m²) | Speed* (m/s)
1 | <200 | <5.6
2 | 200-300 | 5.6-6.4
3 | 300-400 | 6.4-7.0
4 | 400-500 | 7.0-7.5
5 | 500-600 | 7.5-8.0
6 | 600-800 | 8.0-8.8
7 | >800 | >8.8
*Equivalent wind speed at sea level for a Rayleigh distribution

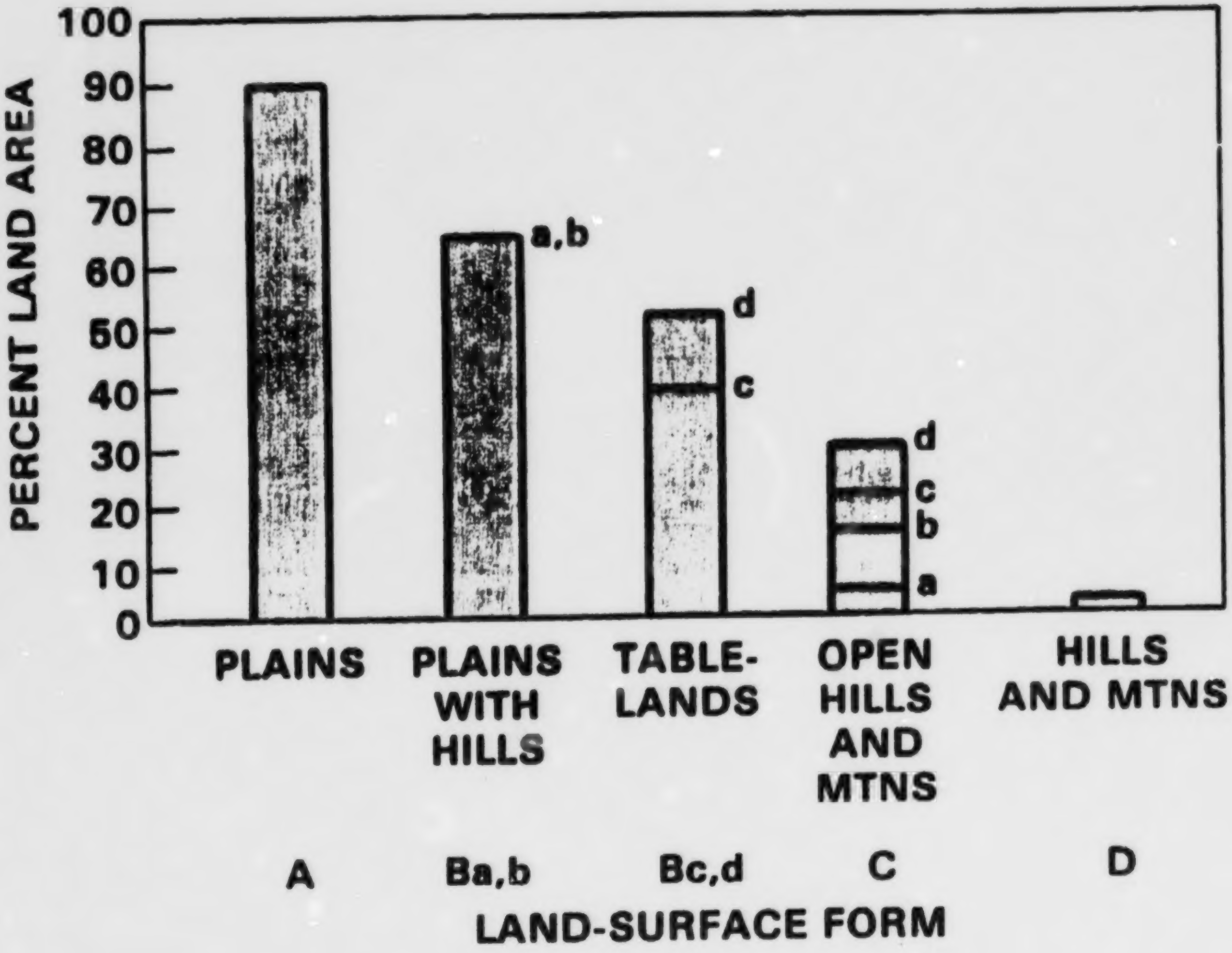
Example of a State Wind Resource Map

Southern California Annual Average Wind Power

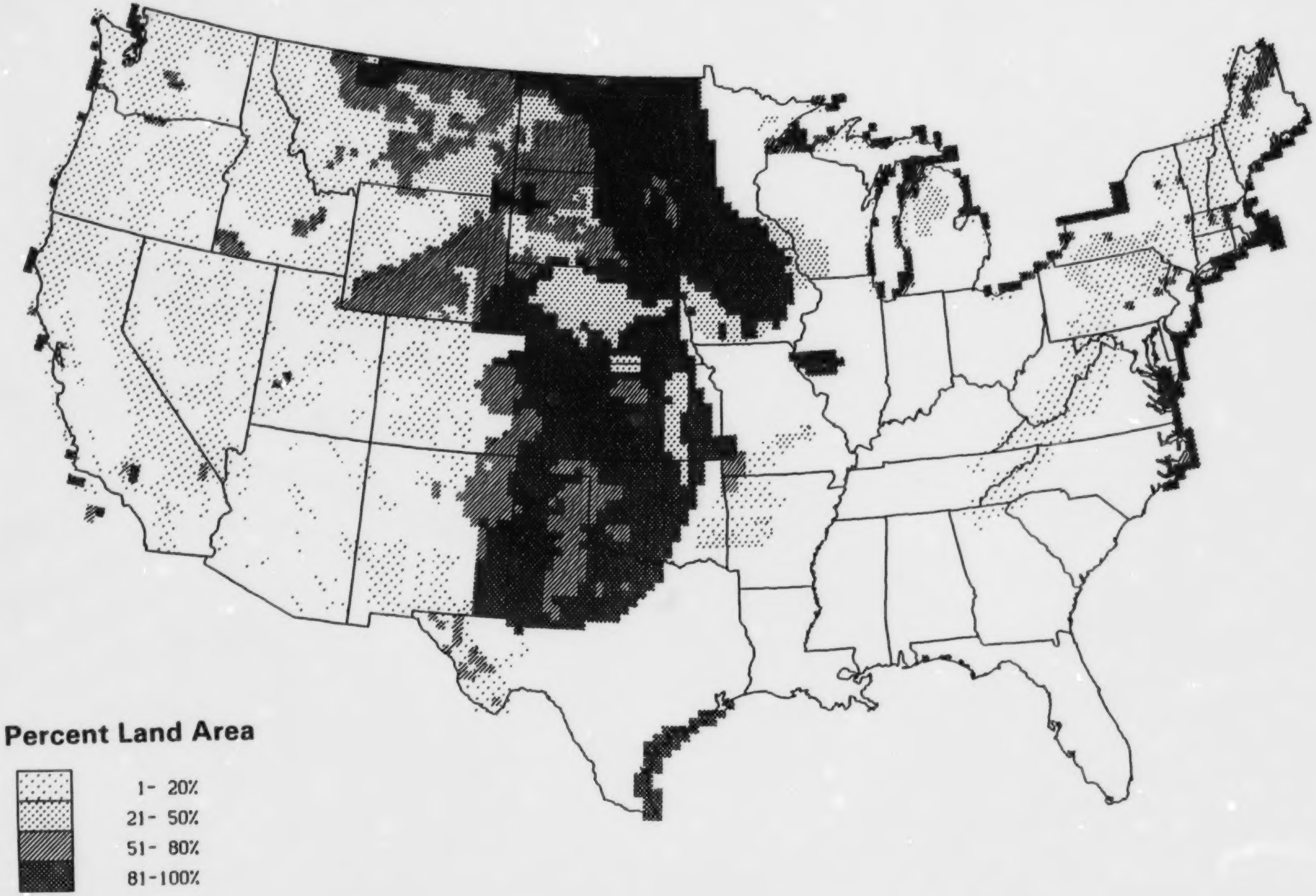

122°
121°
120°
119°
118°
117°
116°
115°
114°
37°
36°
35°
34°
33°
Monterey
Pacheco Pass
Fresno
SAN JOAQUIN VALLEY
SIERRA NEVADA
Bakersfield
TEHACHAPI MTNS
Tehachapi Pass
ANTELOPE VALLEY
MOJAVE
DESERT
Daggett
Needles
San Luis Obispo
Point Conception
Los Angeles
Cajon Pass
San Gorgonio Pass
CHANNEL ISLANDS
LAGUNA MTNS
JACUMBA MTNS
San Diego
0 50 100 Miles
0 50 100 Kilometers
Ridge Crest Estimates

Source: Wind Energy Resource Atlas of the United States

PERCENT LAND AREA FAVORABLE TO WIND TURBINE SITING



Percent Land Area with Class 3 or Higher Wind Resource


Percent Land Area
1- 20%
21- 50%
51- 80%
81-100%

WIND RESOURCE DATA BASE

Source: Wind Energy Resource Atlas of the United States, produced by PNL and published in 1987

- Wind resource - expressed as wind power classes ranging from Class 1 (the lowest) to Class 7 (the highest)
- Annual and seasonal average wind power maps
- Analyzed and gridded versions of wind power maps
- Gridded data - cells of 1/3° longitude by 1/4° latitude
- Certainty rating maps (gridded)
- Percent land area maps (gridded) - annual average only

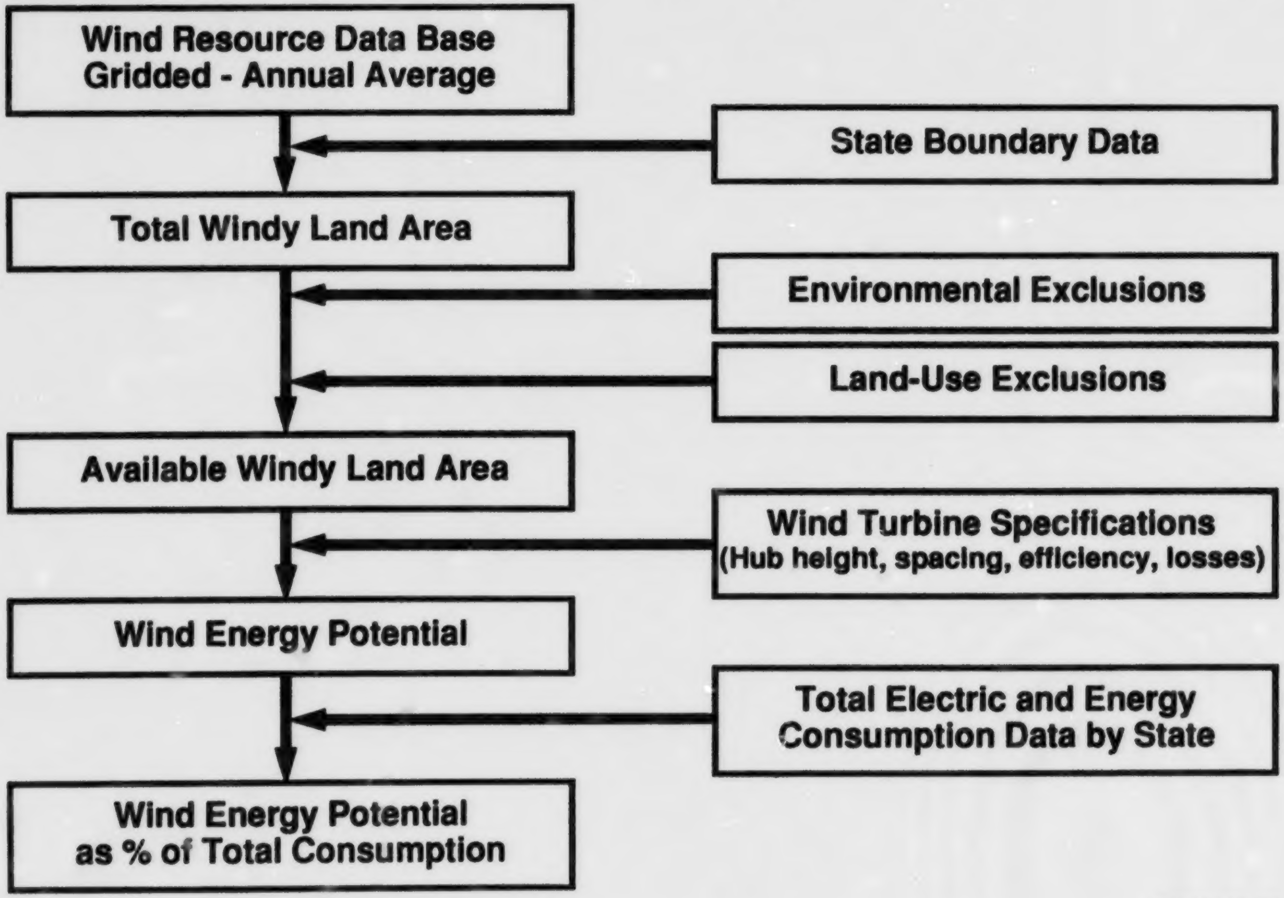
Wind Electric Potential Estimates

Objective

- To estimate the available windy land area and resultant wind electric potential for each state in the contiguous United States and account for lands excluded as a result of environmental and land-use considerations

Wind Electric Potential Estimates

Approach



Wind Resource Data Base
Gridded - Annual Average

State Boundary Data

Total Windy Land Area

Environmental Exclusions

Land-Use Exclusions

Available Windy Land Area

Wind Turbine Specifications
(Hub height, spacing, efficiency, losses)

Wind Energy Potential

Total Electric and Energy
Consumption Data by State

Wind Energy Potential
as % of Total Consumption

S9108046.17

PNL-7789
UC-261

An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States

D. L. Elliott
L. L. Wendell
G. L. Gower

August 1991

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

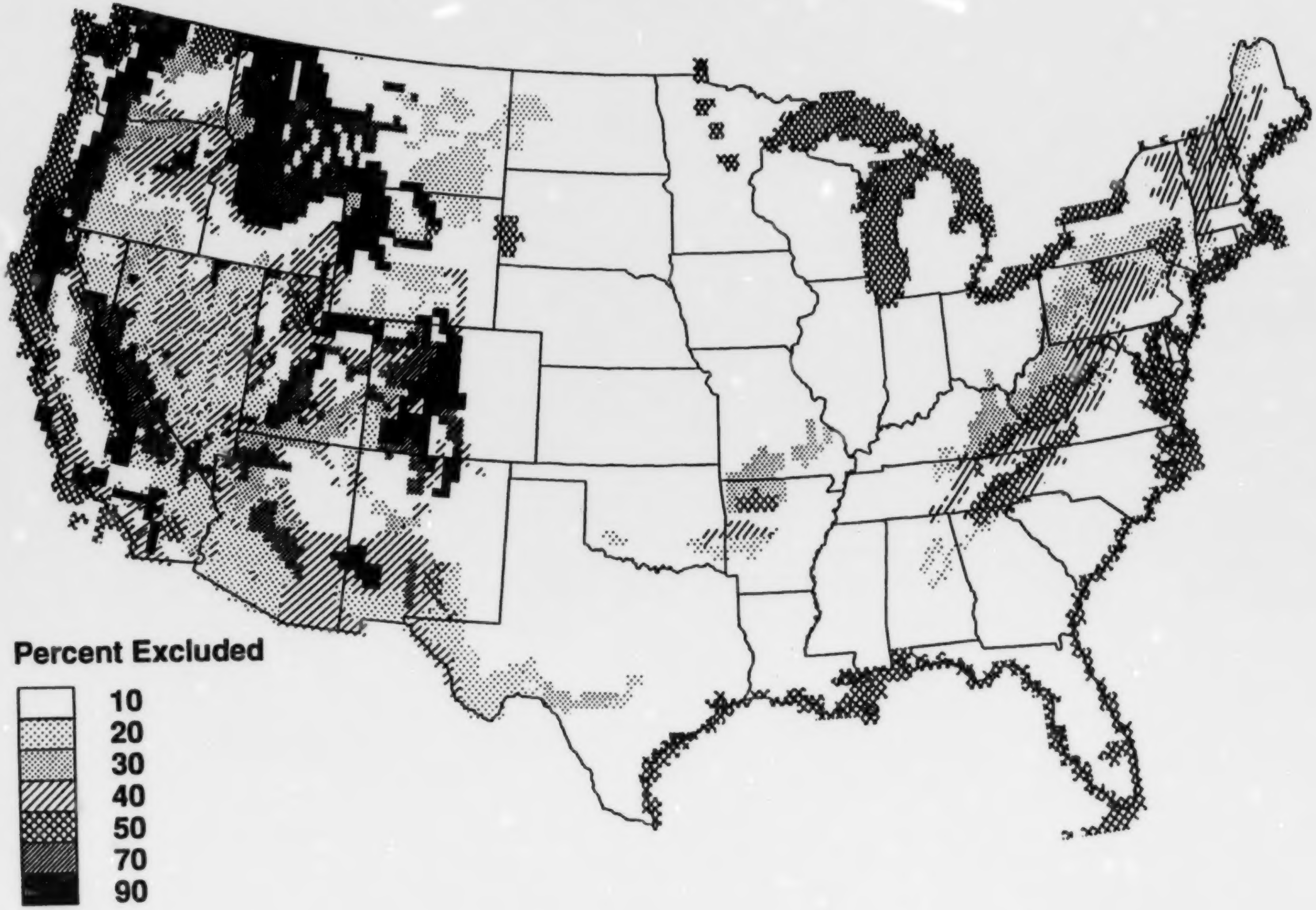
PNL-7789

Environmental Exclusions

- Areas where wind energy developments would be excluded due to environmental considerations include specially designated:
  - Natural areas such as parks, monuments, wilderness areas, etc.
  - Wildlife refuges
  - Recreation areas
- Suitable data base of these environmental areas was not available in digital form
- Observed that environmental lands are most concentrated in mountainous and coastal regions
- Utilized our gridded data on land-surface form to approximate the distribution of environmental exclusion areas
- Evaluated the effect of the environmental exclusions on the windy land area

S9108046. 4

Environmental Exclusion Areas

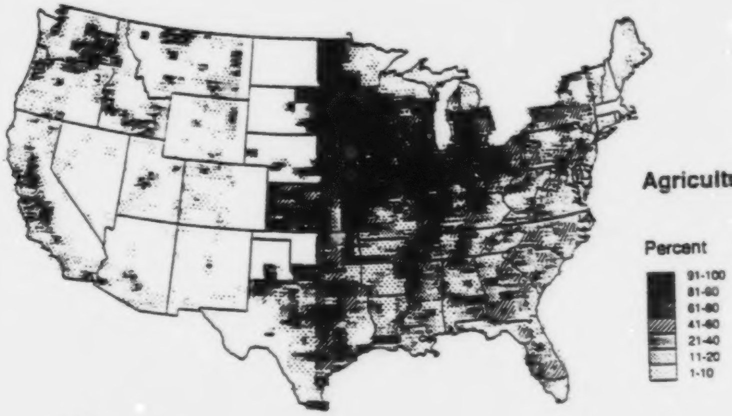

Percent Excluded
10
20
30
40
50
70
90

Land-Use Exclusions

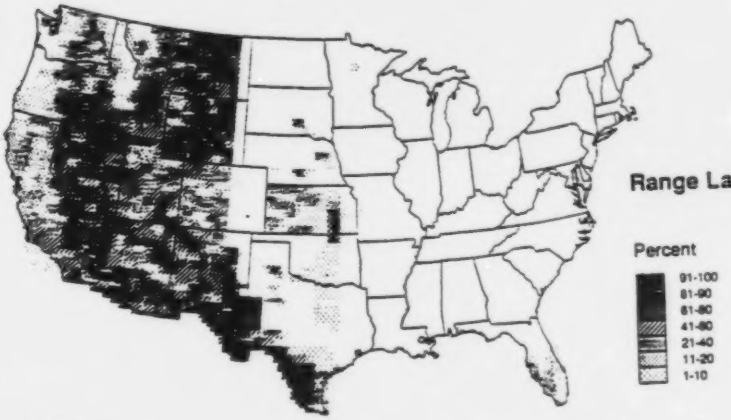
- Obtained a land-use data base that included the percent of grid area for various land-use types, such as agricultural, range, forest, and urban lands
- Converted the land-use data from existing grids of 1/6° latitude by 1/4° longitude to grids of 1/4° latitude by 1/3° longitude for use with wind resource data
- Examined the geographical distribution of the land-use types
- Created various land-use exclusion scenarios to evaluate the effect of different exclusions on the windy land area
- Presented results for two scenarios - a "moderate" and a "severe" land-use restriction

S9108046. 5

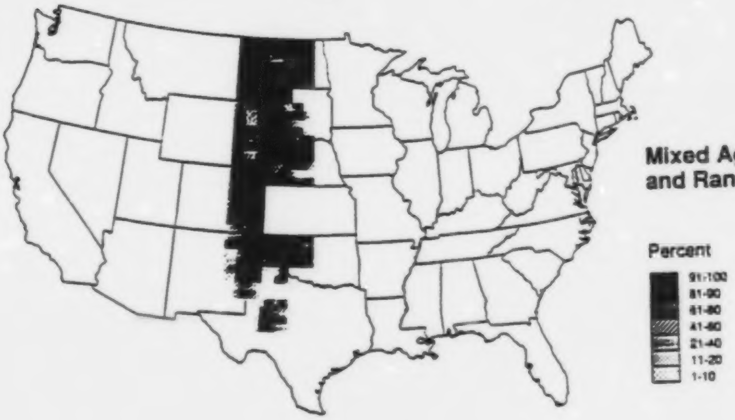
Examples of Gridded Land-Use Data


Percent
91-100
81-90
61-80
41-60
21-40
11-20
1-10

Agricultural Land


Percent
91-100
81-90
61-80
41-60
21-40
11-20
1-10

Range Land


Percent
91-100
81-90
61-80
41-60
21-40
11-20
1-10

Mixed Agricultural and Range Land

Percentage of Land Area Excluded Under Moderate and Severe Land-Use Restrictions

Land-Use Type	Percentage of Land Excluded	
	Moderate	Severe
Forest	50	100
Agriculture	30	100
Range	10	10
Mixed Ag./Range	20	55
Barren	10	10
Wetland	100	100
Urban	100	100

Estimating Available Windy Land Area

The available windy land area in a grid cell may be calculated, for a given wind power class, by:

$$A_W = A_T f_P (1-f_E) (1-f_L)$$

A_T depends on the latitude and the percentage of the grid area that is land and within the state boundary

f_P depends on the wind power class and the land-surface form

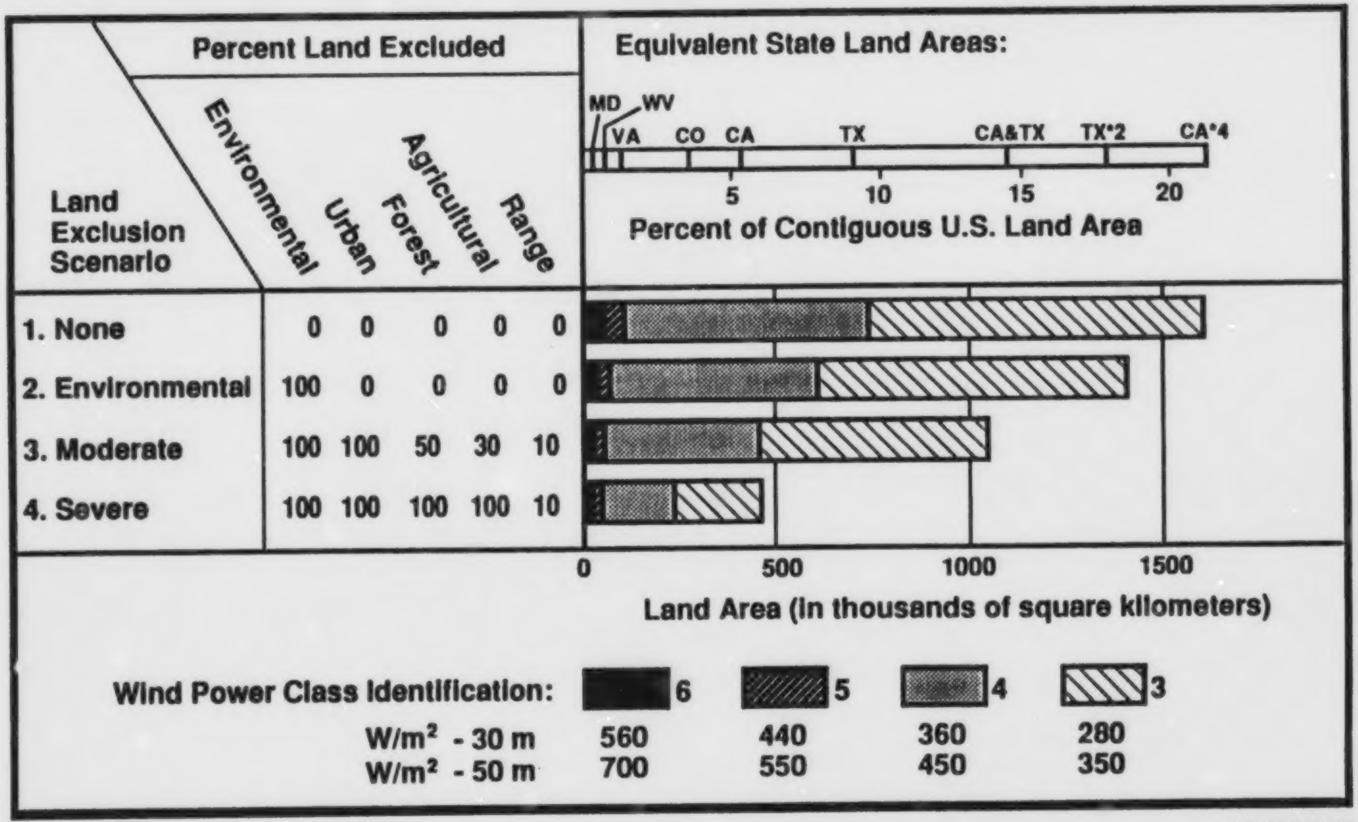
f_E depends on the environmental exclusion

f_L depends on the land-use types and land exclusion scenario (moderate or severe)

The windy land area in a state is calculated by summing A_W for all grid cells in the state, for each designated power class

S9108046.7

Windy Land Area in the Contiguous United States
(Considering Environmental and Land-Use Exclusion Areas)



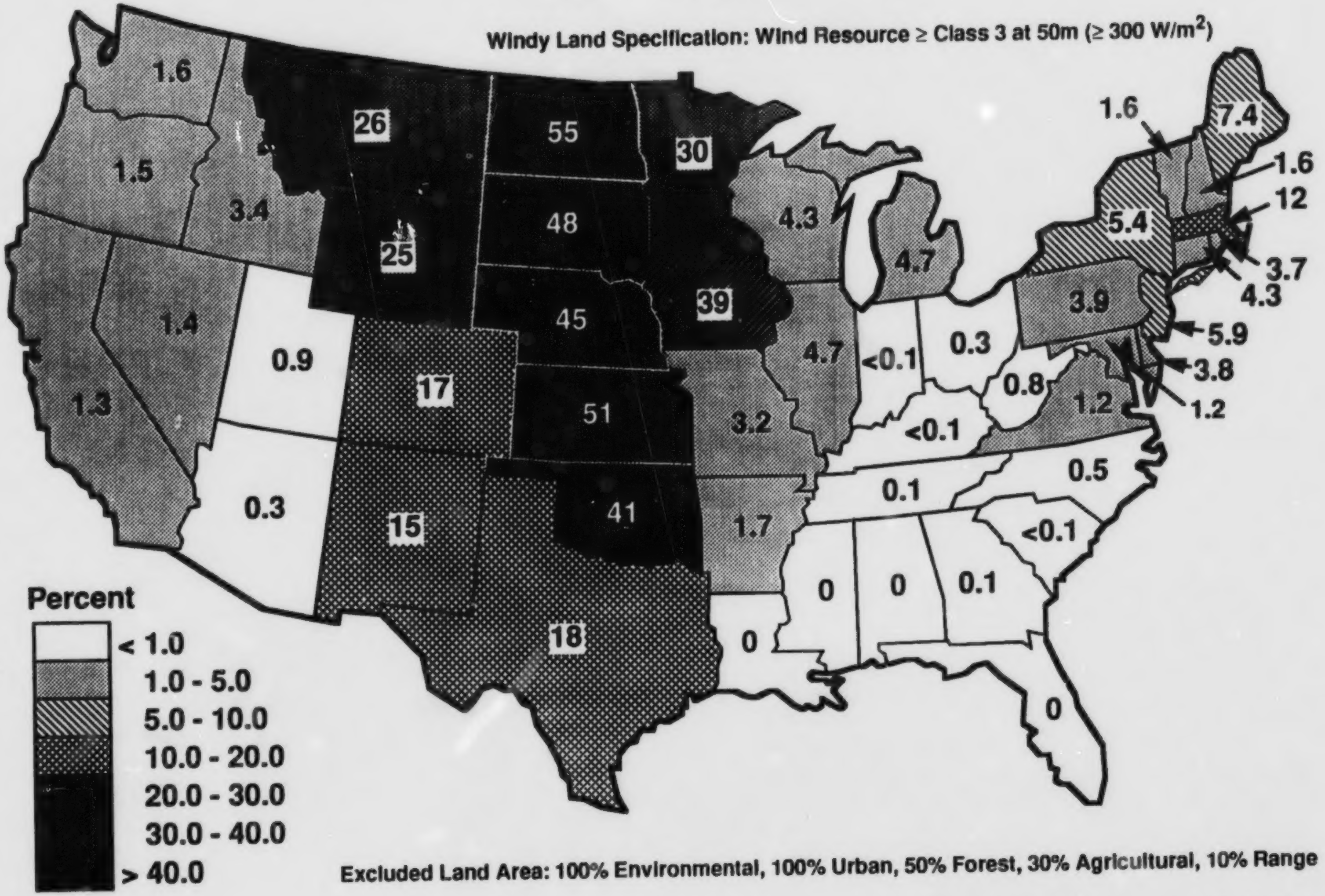
Land Exclusion Scenario	Percent Land Excluded Environmental	Urban	Forest	Agricultural	Range
1. None	0	0	0	0	0
2. Environmental	100	0	0	0	0
3. Moderate	100	100	50	30	10
4. Severe	100	100	100	100	10

Wind Power Class Identification:	■ 6	▩ 5	▒ 4	▨ 3
W/m² - 30 m	560	440	360	280
W/m² - 50 m	700	550	450	350

(S9008069.7B)

Available Windy Land as a Percent of a State's Total Area

Windy Land Specification: Wind Resource ≥ Class 3 at 50m (≥ 300 W/m^2)


1.6
1.5
3.4
1.4
1.3
0.9
0.3
26
25
17
15
55
48
45
51
41
18
30
39
4.3
4.7
4.7
3.2
1.7
0
<0.1
0.3
<0.1
0.8
1.2
0.1
0.5
<0.1
0
0
0.1
0
3.9
5.4
1.6
7.4
1.6
12
3.7
4.3
5.9
3.8
1.2
Percent
< 1.0
1.0 - 5.0
5.0 - 10.0
10.0 - 20.0
20.0 - 30.0
30.0 - 40.0
> 40.0

Excluded Land Area: 100% Environmental, 100% Urban, 50% Forest, 30% Agricultural, 10% Range

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Assumptions for Wind Electric Potential Estimates

- For all scenarios

Turbine spacing	10 D x 5 D
Efficiency	25%
Losses	25%

- For current wind turbine technology scenario

Wind resource	≥ Class 5
Hub height	30 m

- For advanced wind turbine technology scenario

Wind resource	≥ Class 4	≥ Class 3
Hub height	30 m	50 m

S9108046. 8

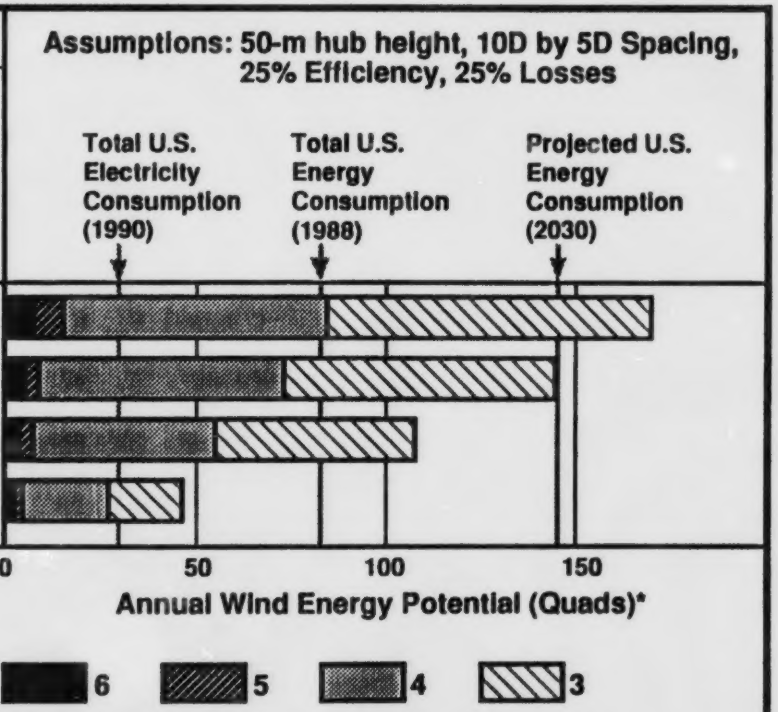
Wind Energy Potential per Square Kilometer of Land Area (by Wind Power Class)

Assumptions: 50-m hub height, 10 D x 5 D spacing, 25% efficiency, and 25% power losses

Power Class	Wind Power Density, W/m^2	Average Power Intercepted, MW/km^2	Average Power Output, MW/km^2	Annual Energy Production million kWh/km^2
3	350	5.50	1.03	9.02
4	450	7.07	1.33	11.65
5	550	8.64	1.62	14.19
6	700	11.00	2.06	18.04
7	900	14.14	2.65	23.21

Wind Energy Potential of the Contiguous United States
(Considering Environmental and Land-Use Exclusion Areas)

Land Exclusion Scenario	Percent Land Excluded: Environmental	Urban	Forest	Agricultural	Range
1. None	0	0	0	0	0
2. Environmental	100	0	0	0	0
3. Moderate	100	100	50	30	10
4. Severe	100	100	100	100	10



* Fossil-Fuel Equivalent Displaced by Wind Systems, Assuming a Thermal Conversion Rate of 10,235 Btu/kWh (average U.S. value in 1988)

(S9008069.6B)

U.S. Wind Energy Potential

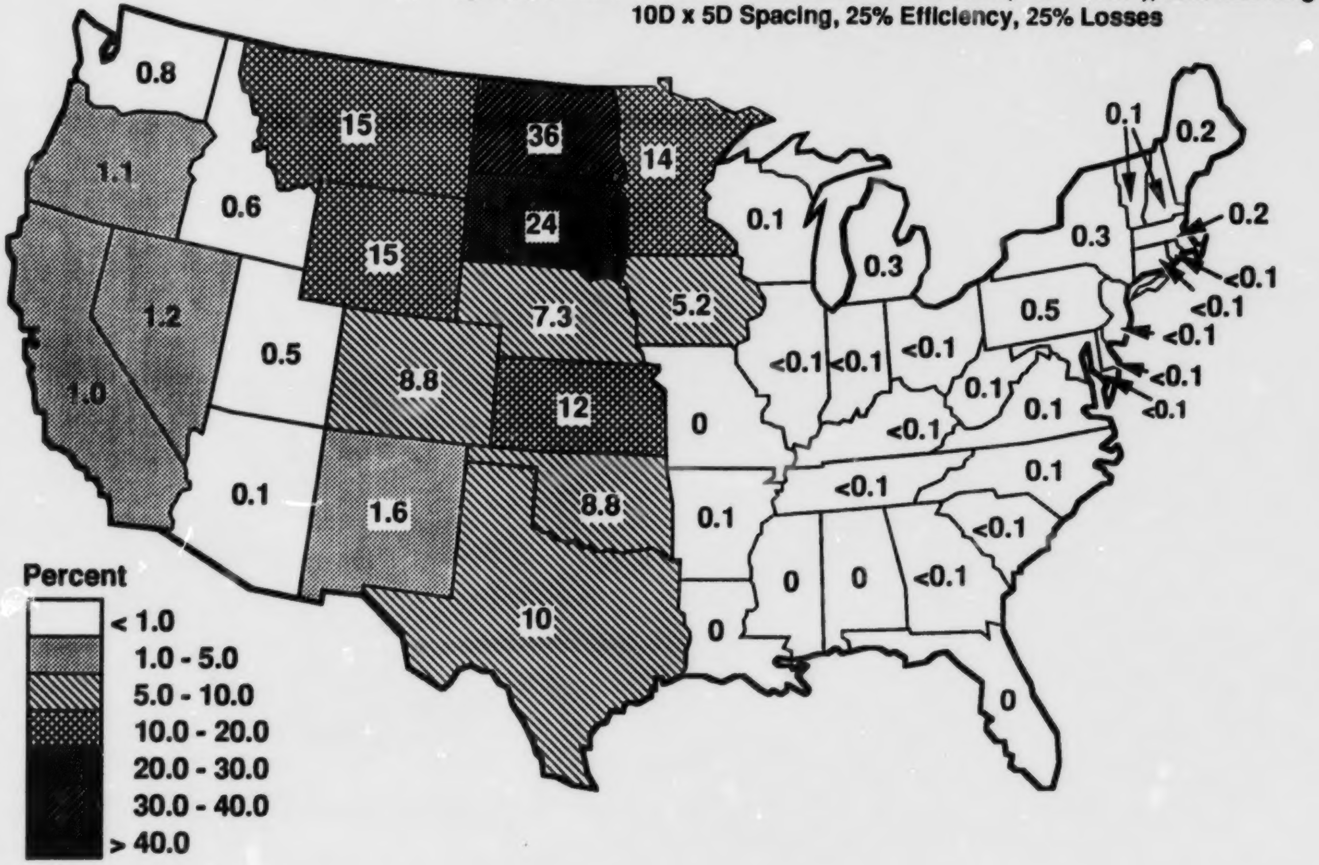
Current vs. Advanced Technology
Moderate Land Exclusion Scenario

	Current Technology	Advanced Technology	
Hub Height	30 m	30 m	50 m
Wind Resource Requirement	≥ Class 5 (> 400 W/m^2 at 30 m)	≥ Class 4 (> 300 W/m^2 at 30 m)	≥ Class 3 (> 300 W/m^2 at 50 m)
Windy Land Area (% of U.S.)	0.6%	6.0%	13.5%
Wind Electric Potential (% of 1990 Electricity)	20%	165%	400%

S9108046.1 1

Wind Electric Potential as a Percent of Contiguous U.S. 1990 Total Electric Consumption

Specifications: Wind Resource ≥ Class 4 at 30m (≥ 320 W/m^2), 30m hub height,
10D x 5D Spacing, 25% Efficiency, 25% Losses

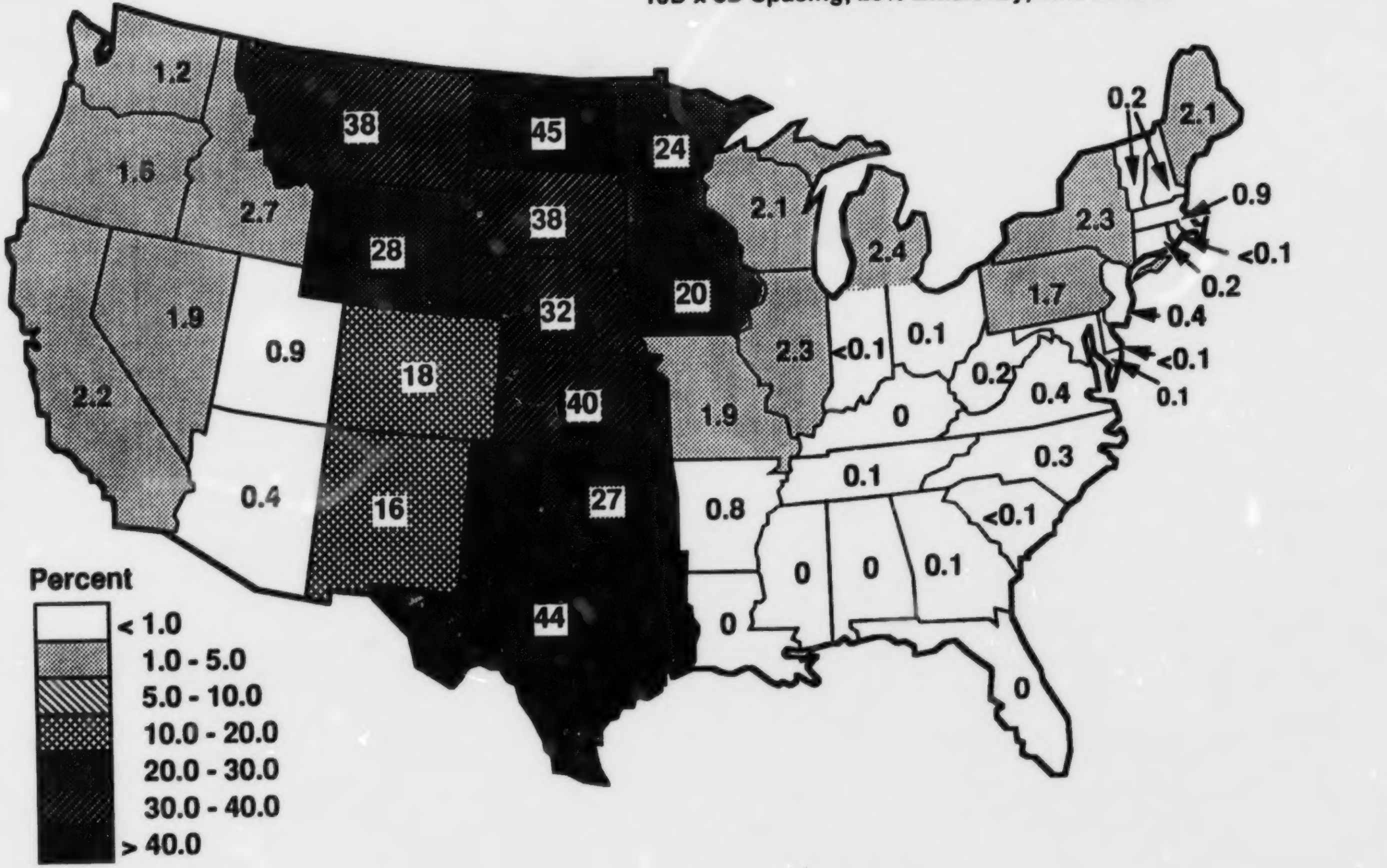

0.8
1.1
0.6
15
36
14
15
24
1.0
1.2
0.5
7.3
5.2
8.8
12
0.1
1.6
8.8
10
0.1
0.3
0.3
0.5
<0.1
<0.1
<0.1
0.1
0.1
<0.1
0
0.1
<0.1
0.1
<0.1
0
0
<0.1
0
0
0.1
0.2
0.2
<0.1
<0.1
<0.1
<0.1
<0.1
Percent
< 1.0
1.0 - 5.0
5.0 - 10.0
10.0 - 20.0
20.0 - 30.0
30.0 - 40.0
> 40.0

Excluded Land Area: 100% Environmental, 100% Urban, 50% Forest, 30% Agricultural, 10% Range

Pacific Northwest Laboratory 8/91 (S9108054.1a)

Wind Electric Potential as a Percent of Contiguous U.S. 1990 Total Electric Consumption

Specifications: Wind Resource ≥ Class 3 at 50m (≥ 300 W/m^2), 50m hub height,
10D x 5D Spacing, 25% Efficiency, 25% Losses


1.2
1.6
2.7
38
45
24
2.2
1.9
0.9
28
38
32
20
2.1
2.4
2.3
<0.1
0.1
2.3
1.7
2.1
0.2
0.9
<0.1
0.2
0.4
<0.1
0.1
0.4
0.3
0.2
18
40
1.9
0
0.4
16
27
0.8
0.1
<0.1
0
0
0.1
44
0
0
Percent
< 1.0
1.0 - 5.0
5.0 - 10.0
10.0 - 20.0
20.0 - 30.0
30.0 - 40.0
> 40.0

Excluded Land Area: 100% Environmental, 100% Urban, 50% Forest, 30% Agricultural, 10% Range

Pacific Northwest Laboratory 8/90 (S9008069.11A)

Conclusions

- Wind energy potential - current technology (wind resource ≥ Class 5, 30-m height)
  - 20% of U.S. electric consumption from only 0.6% of U.S. land
  - 3 states (ND, WY, MT) contain 80% of the U.S. potential
  - Current wind energy production (1990) only 0.5% of the U.S. potential

- Wind energy potential - advanced technology (wind resource ≥ Class 3, 50-m height)
  - Over 100 quads (fossil-fuel equivalent) of electric energy
  - 12 contiguous states contain over 90% of the U.S. potential
  - 36 states with >10% of their own electric consumption

S9108046.1 3

Factors Not Examined in This Study

- Remoteness of the resource
  - Transmission constraints
  - Access - - roads, terrain, weather
- Match between production and demand
  - Seasonal wind resources vs. loads
  - Diurnal wind resources vs. loads
- Intermittency of the resource
  - Integration issues with utilities
  - Storage systems
- Utility and public acceptance
- Local ordinances, zoning
- Other institutional constraints or opportunities

S9108046. 3

Refinements Needed

- Actual data on environmental exclusion areas
- Current land-use data base
- Seasonal analyses of the wind potential
- Improved terrain resolution
- Inclusion of other factors, such as access and transmission constraints

Paper for presentation at the Canadian Wind Energy Conference Windpower'91
Montreal, Quebec, Canada, Nov. 4-7, 1991

WIND ENERGY POLICY, APPLICATION AND POTENTIAL. AN OUTLOOK BASED ON THE CASE STORY OF DENMARK

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Denmark

Abstract

The paper deals with the connection between environmental and social cost issues and energy policy in the application of wind energy. The paper outlines the issues of the global energy problem and environmental and social costs, with emphasis on legislation. The case story of Denmark is outlined in view of the recent action plan Energy 2000 in terms of present application of wind energy and future potential. A strategy for the implementation of wind energy is outlined.

1. INTRODUCTION

During the last two to three decades of this century wind power has been introduced in the electrical supply world wide at an ever increasing rate, and this development is continuing. At the same time there has been (and there still is) a continuous debate on the pro's and con's of wind power. In almost any actual specific case the economic consideration entering into the decisions to use or not to use wind energy have been based on economic criteria in the usual narrow sense, i.e. cost/benefit analysis using the criteria of traditional power supply.

Even today decisions are based on economic criteria in terms of cost/kWh, where environmental or social cost/benefits do not in general enter the formal calculations, and this is true regardless of whether the wind energy installation in question is a large grid connected wind turbine in a California wind farm or a small wind turbine on a remote diesel grid in a third world country. Environmental and social cost/benefits at best enter the decision indirectly as a politically determined selling price from the wind power plants.

The paper outlines the issue of the global supply problem and the changes in the public perceptions that seem to take place these years, characterized by an increasing awareness of the environmental and social issues. These issues are discussed, and the legislation in this area is shown to be mainly of an indirect type, the general lack of direct legislation maybe reflecting the difficulties in quantifying the matter. This leads to the realization of the importance of the policy issue.

The case story of Denmark is briefly outlined. Here a serious energy policy has during more than a decade produced the worlds largest per capita wind energy contribution to the national energy supply. The case story is described in terms of the present application of wind energy and the future potential in view of a recently adopted national energy plan, Energy 2000, that aims at a 10 wind energy contribution to the Danish electricity supply in year 2000. Based on this a strategy for the implementation of wind energy is outlined.

2. THE ENERGY PROBLEM

On a global level the present energy situation may briefly and maybe superficially be characterized by a very high energy consumption in the industrialized capitalist countries, an equally high but much less efficient energy consumption in the industrialized socialist (or former socialist) countries and a low energy consumption in the third world. This is true both in absolute terms and per capita, and broadly speaking the major energy source by far is the group of fossil fuels, with a considerable portion of wood-burning in the third world. All other energy sources are marginal on a global level.

Thus the distribution of energy consumption levels to some extent corresponds to the distribution in material standards of living, and this correlation is generally accepted as a factual thing, i.e. a high standard of living corresponds to (or requires, but does not necessarily guarantee) a high level of energy consumption. Energy savings measures and more energy efficient equipments or procedures may reduce the "proportionality factor" between standard of living and level of energy consumption, but in a world of increasing overall standard of living these measures will delay the occurrence of a certain level of energy consumption, not avoid it.

It may be argued whether or not we have a world in which the overall standard of living is increasing, but it should not be questioned that everybody (especially the 2nd and the 3rd world) wants it to increase. With this wish follows the wish that the global energy consumption should increase, although maybe at a different rate than todays increase.

At the same time, the increasing level of energy consumption implies an increased level of environmental damage and social cost, at least if the mix of energy sources does not change away from the dominance of fossil fuels and wood. At the present time (1991) the major concerns associated with the use of fossil fuels are 1) the risk for climatic changes due to emissions particularly CO_2 emissions, often paraphrased as "the green house effect" 2) property damage, including forests, land and lakes, due to acid rain caused primarily by the burning of coal 3) health problems caused by pollution of air, soil and water. Thus, with the wish to increase the global standard of living comes the consequences a) increased energy consumption and b) increased environmental and social cost.

It seems that the public of the rich countries, the industrialized ones with the high energy consumption, realize that the 2nd and 3rd world countries must increase their standard of living very considerably. If not, the world will experience grave social and political problems due to the tensions between rich and poor countries. These problems may eventually develop into real (maybe armed) conflicts and if nothing else this perspective raises serious questions as to how far the rich countries can go to maintain a difference perceived as "unfair" many people, and still maintain their feeling of being morally intact. Thus, if the consequences of the increased energy consumption should be avoided by halting the increase in standard of living, other consequences follow which are just as severe, although very different.

This is the "Hobson's Choice" which we face. The only solution to this is to burn less fossil fuel, not more, and to leave a considerably portion of the fossil fuel "quota" that our planet can absorb to the third world countries. This has been most clearly stated in the "Brundtland" report [9].

Judging from everyday sources of information it seems that the public in the western countries accept as facts 1) the need for increased standard of living in the 2nd and 3rd world 2) the green house effect, acid rain and health consequences of fossil fuels while at the same time 3) it does **not** intend to limit the growth of (let alone reduce) its own standard of living. This is not necessarily government positions but it is increasingly the public opinion, and it represents a growing awareness of the environmental issues.

This position clearly implies a conflict or inconsistency with the present mix of energy sources. Wind energy (and other renewables as well) comes as an energy source that may contribute to the alleviation of this conflict. However, even with a wide range of tools to quantify these issues there will still be issues that must be solved by political decisions. Therefore the need for an energy policy.

3. ENVIRONMENTAL AND SOCIAL COSTS

It appears from the preceding section that environmental and social issues must be considered in addition to the traditional economic considerations. While this remains basically a political decision process it seems reasonable to rationalize the decision process by incorporating as far as possible these issues in a quantitative manner in the traditional economic calculations, i.e. in terms of costs and benefits (also expressed in costs). This is dealt with briefly in the first subsection.

In cases where this does not lead to the (politically) desired results the environmental and social aspects can be imposed by legislation. This can be done by "direct legislation" which in this paper is used as the term for legislation that intends to define directly the influence on environment and society of the use of wind energy. This is dealt with in the second subsection. Alternatively it can be done by "indirect legislation", which is used as the term for legislation that intends to influence the use of wind energy in terms of restrictions, incentives or enforcements that do not reflect directly the influence on environment or society. This legislation turns out to be the most common as it does not need to solve the difficult tasks of assigning a realistic value to environmental or social effects, but rather to impose mechanisms that leads to the desired and politically defined result.

3.1 Assessment of Environmental and Social Costs

This is a brief discussion of the assessment of environmental and social costs (and benefits) of using wind energy. Primarily the goal of such assessment is to evaluate the impact of wind energy in terms of economic quantities so that the outcome of a traditional economic calculation will more accurately reflect the costs and benefits of using wind energy. This way the traditional decision process will by itself include wind energy where it is truly economical, everything considered and including environmental and social costs.

This is really a formidable task and few have attempted to carry it through. Probably the most prominent attempt is the study of Hohmeyer [3], which in the framework of Germany compares the cost to society (which includes environmental costs) of fossil fuel energy to wind energy and other renewables.

This way the social cost of wind energy actually emerges as a saving per kWh, which is obtained if wind energy is used instead of fossil fuel in the mix used 1988. This is a relevant measure, since economic criteria most often compare the use of wind energy to the use of fossil fuel. Hohmeyer covers a wide range of scenario's and the social cost changes considerably with the scenario's.

The study concludes that when the positive and negative effects of electricity generated on the basis of wind energy are considered (with the external costs of present electricity generation included as avoided cost) the total external benefits including environmental ones exceed 0.06 DM per kWh. This corresponds to an amount of approximately ECU 0.030 or US$ 0.035 per kWh which may safely be ascribed to the use of wind energy.

Even these "safe" numbers are high, considering that in Denmark a modern wind turbine will produce power at a traditional cost of approx. 0.070 US$/kWh at a Class 1 side, a decent but not exceedingly good site. Corrected by Hohmeyer's "Safe" estimate the cost would be approx. 0.035 US$/kWh, a very competitive cost in the Danish market. This indicates that including the true environmental and social costs of wind energy into the economic analysis would significantly influence the decision process in favor of wind energy, and this finding is supported by a recent Dutch study reported by Winsemius [2].

However, the inclusion of these costs are presently in general not accepted by decision makers, and the present wind energy implementation rate does not reflect the fuel impact of these costs. Where legislation on environmental and social issues is enforced these costs may be represented to some degree.

3.2 Direct Legislation

There is presently in Europe a quite modest amount of legislation directly in terms of the environmental and social costs. The most common type of legislation is concerned with noise, i.e. environmental effect rather than cost. The most influential direct legislation presently in the making is concerned with the CO_2-emissions, in terms of environmental and social cost.

Noise

Noise from wind turbines is a prominent issue in many wind turbine siting decision. Therefore, in European countries with a significant amount of wind turbines in operation, noise regulations have been established. Clarke et.al [3] lists maximum noise limits for Denmark, Sweden, Holland and Germany (Schleswig-Holstein). The limits are typically 35-45 dB(A) in specified distances from a wind turbine.

Noise is a difficult subject as noise is perceived in a subjective way. The Danish noise regulation [4] contains an Appendix in which the measurement procedure is defined and formulae are specified to calculate noise levels at various locations.

CO_2 - Tax

In Europe the growing concern for the green house effect has prompted the European Community (EC) to aim at the introduction of a general tax on the emission of carbon dioxide, CO_2, from the burning of fossil fuels. The status for the EC tax is

- It has been decided to impose a CO_2 tax intended to reflect to some degree the environmental and social cost of burning fossil fuels.

- It has been decided to impose the tax in terms of ECU per ton CO_2 emitted. The amount is being negotiated between the EC countries and will probably be of the order 20 ECU per ton CO_2 (approx 25 US$/ton CO_2).

- It has not yet been decided when the tax is going into effect. Probably the tax will be enforced from the opening of the internal EC marked in January 1993. Most probably the tax will be introduced at a lower rate, gradually increasing to its final level.

The CO_2 - tax is intended to replace a system of national CO_2 - emission quotas which was proposed as part of implementing an EC goal of stabilizing the CO_2 - emissions at a stationary level in year 2000. The proposed system of quotas was rejected by the member countries. A few European countries have already enforced CO_2 - taxes or are in the process of doing so:

Sweden has a CO_2 tax of the order 30 ECU per ton CO_2 /approx 40 US$ per ton CO_2)

Denmark is presently (late 1991) processing a CO_2 - tax in parliament. The proposed tax is of the order 7 ECU per ton CO_2 (approx 8 US$ per ton CO_2), a level which is chosen with the aim of harmonizing the Danish tax level with the expected start level of the EC tax. With the present mix of electricity generation the proposed tax will correspond to 0.006 ECU/kWh electricity (approx 0.008 IS$/kWh).

Reduction of electricity tax

In Denmark there is a general tax on electricity, introduced in 1977 with the aim of reducing the use of (imported) fossil fuel. From 1986 the tax level has been approx 0.04 ECU/kWh (0.05 US$/kW) out of a total electricity cost of approx 0.13 ECU/kWh (0.15 US$/kWh). For wind turbines there is a reduction of this electricity tax, intended to reflect the positive effects on the environment. The rules are quite complex, but in general approx 0.03 ECU/kWh (0.04 US$/kWh) is paid back to the wind turbine operator.

3.3 Indirect Legislation

The area of indirect legislation is not a well defined one. It covers legislation for subsidies to make wind energy market competitive in the traditional sense, land use and preservation legislation and R&D grants for development of wind energy technology and application.

In a wider sense it also includes action plans and agreements that may serve as incentives for a desired development, but not necessarily cast in the form of legislation. In the end the are borders on the discussion of available means to obtain the desired ends. A number of examples from Denmark are given below, Many of them have European parallels, in particular within the frame work of EC.

Subsidies

Government subsidies for the installation and application of wind energy have been given in the period 1979-1989. Initially the level of subsidy was 30 of total cost, which made wind energy market competitive at the time. Later it was reduced, to disappear in 1989 when wind turbines became market competitive in Denmark on their own.

In addition to this the electric utility companies have shared the expenses of grid connection and reinforcement. Presently utility contribution is 35 of these costs. Finally the pay-back rate is sometimes claimed to contain a (small) hidden subsidy from the utilities. Also the quite complicated tax rules for wind turbine operators contain an element of government subsidy.

The total government subsidy 1980-1990 was of the order 35 mill ECU (42 Mill US$).

R&D Programmes

Government supported R&D is a major source of indirect subsidy for wind energy. The Energy R&D Programme in Denmark spent of the order 22 Mill ECU (27 Mill US$) during 1980-1990 in wind energy related R&D projects. It should be noted that similar subsides exist for other type of power generation.

Other Programmes

In addition to direct subsidy and R&D programmes Denmark spent some 21 Mill ECU (25 Mill US$) on other wind energy related programmes, including the operation of The Test Station for Wind Turbines as a free-of-charge service for the wind energy community. Altogether the Danish Governments Wind Energy support programme spent some 77 Mill ECU (95 Mill US$) during 1980 -1990. The legislation in this context is an indirect legislation for environmental and social costs, since these were the reasons for the Danish wind energy policy.

Planning exercises

If a high proportion of wind energy is to be obtained, land must be available. This implies the combination of many conflicting interests and view points into plans for land use and preservation. In 1981-86 a planning exercise for large scale wind turbines was undertaken by the Danish Planning Agency [5]. Later on, in 1991, the Danish Planning Agency published a study [6] on the possibility of placing 100 MW of utility operated commercial wind turbine parks in addition to an already installed quota of 100 MW.

Agreements

The first 100 MW agreement between the Ministry of Energy and the Danish Utilities was made in 1985. It called for the installation of 100 MW wind energy as part of the normal electricity production system before 1990, and the agreement will be completely fulfilled during 1991. Preparation of a second 100 MW agreement is underway [6].

Planning legislation

Now planning legislation will be enforced in Denmark from January 1992, based on experience with the first 100 MW agreement and as a prerequisite for a second one. The new legislation has simplified procedures and a more streamlined layout, making it more operational in the context of large scale wind energy application.

4. APPLICATION AND POTENTIAL: CASE STORY DENMARK

As already mentioned the inclusion of wind energy in a nation's energy supply for reasons of environmental and social costs will strongly benefit from, if not presuppose, a national energy policy.

Denmark instated a national energy policy including wind energy as early as in the mid 1970's. The result is that today wind energy is an acknowledged part of the Danish energy supply system, and there is a sustained political will to maintain that position. This political will and intent is demonstrated by "Energy 2000" [7], an action plan for a development of an environment conscious energy policy that allows continued economic growth.

The following two subsections outline the application of and potential for wind energy in Denmark. So far the application of wind energy have resulted in an installed capacity of 343 MW at the end of 1990 with a stable rate of increase of 70-90 MW per year. The action plan Energy 2000 [7] operates with 3 scenarios, resulting in estimated installed wind power capacities in 2000 of 800-950 and 1350 MW, respectively. The rate of increase registered under the "old" policy already is between the middle and the high scenarios.

4.1. Application in Denmark

The majority of Danish wind turbines are grid connected, and Danish utility statistics therefore cover the installed wind power capacity quite accurately. At the end of 1990 status was:

Installed capacity	343 MW
Number of wind turbines	2881
Energy production 1990	604 GWh
Proportion of total DK electricity	2
Average turbine size (all)	118 kW
Average turbine size (installed 1990)	199 kW

Availability of the installations was in the range 95 to 99 Pct, and the development of the application has been characterized by:

- A narrowing of concept choices. From the multitude of concepts around 1980 to two in 1990: The 3 bladed "Danish wind turbine" with stall control or pitch control.
- An upscaling from 55 to 450 kW. Around 1980 the "Danish wind turbine concept" emerged in sizes around 10 kW, rapidly increasing to 55 kW. This became a standard wind turbine 1980-1985, but during 1985-90 the size increased from 55 to 450 kW, a factor of 8.

- Development of design areas such as blades, controls, power trains, towers etc.

- Development of a certification procedure. Around 1980 the certification was mainly an engineering review procedure to evaluate if the design qualified for subsidy. In 1990 the Danish certification system is considered the most extensive and technically best supported certification system for wind turbines in the world.

As mentioned in section 3 the development is assisted by government subsidies of various kinds, including establishing and operating the Risø Test Station. When looking at the total cost of the government programme: 78 Mill ECU (95 Mill US$) for the 10 year period 1980-1990 the cost has been modest considering that the outcome has been:

* A consistent home market, presently of some 70 MW/year
* A world leading wind turbine industry
* A present wind energy contribution of 2 Pct
* A projected wind energy contribution of 10 year 2000.

The most important explanation is that the government programme has had a great variety of components. The most important component by far is **the direct government subsidy** (section 3) which compensated for the initial lack of market competitiveness. This was enhanced by a network of institutions including the Risø Test Station.

In addition to the Danish government programme EC has supported the wind energy technology application and development through grants from DG12 (R&D) and DG17 (Demonstration).

4.2 Potential in Denmark

The framework for the future energy policy in Denmark - and therefore also for the potential development - is the Energy 2000 Action Plan [7]. The reasoning behind the Action Plan is centered almost entirely on environmental and social issues such as those outlined in Section 1 and contains little reference to business related issues. The action plan operates with three development scenarios , used as three different frameworks for the prediction of trends, evaluation of expected problems and estimation of necessary R&D topics. The scenarios are:

Scenario	Installed year 2000	Increase MW/year
Low (supply)	800	46
Medium (economy)	950	61
High (environment	1350	100

The three scenario's reflect three different priorities:

The Supply Scenario has main emphasis on changes in the supply structure and the use of fuel. This is "the easy" scenario.

The Economy Scenario has social economic considerations as first priority.

The Environment Scenario concentrates the effort on reducing the environmental impact, in particular CO_2 emissions. Therefore it is combined with a high priority on energy savings.

During the years 1988 to 1991 the rate of increase in installed wind power capacity has been a stable 70 to 90 MW/year. This means that even in the "old" energy policy the actual rate of increase was between the economy and the environment scenarios, even after direct subsidy vanished in 1989.

The Energy 20000 Action Plan identifies a number of technological development trends that are considered necessary in order to realize the environment scenario. Examples are:

- More silent wind turbines
- Larger cost/effective wind turbines
- Visual accept of wind turbine clusters
- Economy of wind power
- Commercially viable energy storage systems.

It is envisaged that the economy of wind power might increase by 40 Pct year 2000.

The action plan identifies a number of barriers that may prevent or counteract the desired development. It also lists a number of actions that may ensure the environment scenario in year 2000 within topics such as:

- Grid connection and pay-back rates. Firm predictable rates are necessary for private investors. This means that tariffs must be defined and maintained for 10-15 years.

- Siting possibilities. A new siting investigation for 1500 MW wind is ongoing, and the result will show if existing criteria must be changed in order to secure sufficient space.

- Popular accept of wind turbines. This implies issues of noise, visual impact etc. Honest information to the public on pro's and con's is considered vital.

- Financing of wind turbine. Rules must be established that ensure that wind turbines can be financed in the normal Danish system used to finance and insure property.

- Administration of wind turbine legislation. Specific rules may have to be adjusted to ensure the desired result.

- Wind turbine economy. Comparison of cost/kWh from wind turbines with the cost from traditional supply may be more realistic if more broad social economic considerations - including CO_2 reduction caused by wind turbines - are applied.

These actions would seem entirely realistic and possible in the presence of an energy policy, but it would hardly seem realistic to expect this development based on the normal market mechanisms alone.

5. OUTLINE OF A STRATEGY

The energy problems outlined in Section 2 would seem to be globally applicable. The assessment and application of environmental and social cost as outlined in Section 3 are in the process of being accepted and implemented in Europe, to a considerable extent within the framework of EC. The implementation of an energy policy as the one outlined for Denmark in Section 4 is not unique, several other countries have or are in the process of establishing an energy policy with a wind energy component.

The public perception of the problems in the western societies, as outlined in Section 2, actually calls for a strategy to deal with the increasing public awareness of the problems. This awareness seems now to be in the process of being converted into increasingly clear requirements to the political systems:

- Provide energy enough to ensure a proper and "just" global distribution of wealth (standard of living)

- Provide this (enormous amount of extra) energy in such a way that the environmental and social costs are acceptable.

- Do not reduce our western standard of living in the process.

This could actually be seen as the outline of a global strategy, but it does not devise technical or political solutions. The global strategy requires a number of measures to be taken, and prominent among them would in the long run seem to be a) energy conservation and savings and b) use of renewable energy to the largest possible degree.

This will require the development and application of energy policies and each policy will require action plans. Each "community" should contribute their expertise towards establishing these plans, the "wind community" obviously contributing to the creation of action plans to utilize wind energy.

Recently the European Wind Energy Association EWEA issued a strategy document [8] aiming at exactly that. The EWEA strategy document intends on an European scale to contribute to the creation of a more prominent role for wind energy in the European energy policy.

6.CONCLUSION

This paper has focussed on the importance of the environmental and social issues in the energy policies necessary to solve the global energy problem. One important issue has been the inclusion of environmental and social costs in the decision process in order to represent wind energy properly in the energy supply.

The case story of Denmark has been used as a successful example of such energy policies. However, it is interesting to note that if it is realistic to assume the 40 Pct reduction in the cost of wind power as it is done in the Danish Energy Plan 3000 [7] then wind power will be economically competitive even without the environmental and social considerations. Indeed, in his study [1] Hohmeyer claims that this is already the case in Germany today. This would indicate that solid information to decision makers should be an important part of any strategy to apply wind energy, and this is strongly reflected in the EWEA strategy document [8]. .

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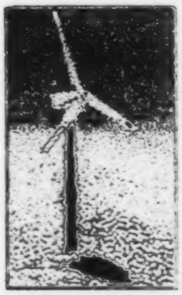

INDUSTRY AND THE ENVIRONMENT

Industrial Initiatives in the Wind Industry

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What are Industrial Initiative's?

Industrial initiatives are, in blunt terms, methods of lobbying and marketing to increase the activity, revenues, profits, and commercial viability of an industry. They may be undertaken by industry individuals/firms, industry groups, government agencies, or combinations of all of these.

Why should they be done?

Industrial initiatives are required to increase awareness of the industry, to bring first-hand knowledge of the capabilities of the industry directly to potential customers or users, and to increase understanding of the industry and the capabilities of the technology by 'outsiders', including customers, utilities, governments, financing agencies and institutions, and the media.

They may also be done because there is a willingness, a need, an interest in the development of a Canadian industry, with domestic capability, domestic and export markets, and because the domestic industry does not wish to be smothered by foreign interests, big business from other countries, to become mere operators of technology which we missed the boat on.

How do you do them?

You spend money. Sometimes lots of it. You do your best to leverage the funds and resources you do have, with other agencies and existing programs. You also spend time. The activities range all over from forming industrial organizations, to user organizations, to letter-writing campaigns, to press releases, booklet publishing, to public speaking, to meeting with politicians, to interventions, to demonstrations, and on and on…

Historical Activities in Canada

The initiation of CanWEA itself is a prime example of an industrial initiative, one that was done in partnership with the federal government. Most of you are probably aware that in 1984, the efforts of the outgoing NRC, the incoming EMR people responsible for wind energy, coupled with the leaders of the industry and some very interested and dedicated individuals, made CanWEA happen. CanWEA has had its ups and downs, in terms of industrial initiative activities, over the years, but it has been a central voice, and an important voice, in such activities. It has been small, but - just like our industry - it has survived so far, and is today becoming a more important vehicle in these activities. This is witnessed by our increased membership, increased success and attendance at conferences, and the public and political role that CanWEA has increasingly taken, particularly this past year.

There are other activities which have been undertaken. A number of firms and individuals have made use of TIP funding and IRAPs. TIP or Technology Inflow Programs were sponsored by External Affairs and have been used to visit factories and facilities outside of Canada with the intention of licensing the foreign technology, for manufacture in Canada. This is a way to bring activity to our country, develop domestic expertise, all without spending domestic R&D, yet providing real industrial opportunities at home. In other words, this is not just installing someone else's equipment, this is learning about it, perhaps installing some units to be sure this is right, then investing in it for manufacture in Canada. IRAPs are Industrial Research Assistance Programs and are used as partnerships with government to develop or adapt new technologies, design new equipment, etc. Firms in Canada have used these for tower designs and other activities. Such partnerships with government, initiated by industry, are prime examples of our industry taking the future into our hands, and seizing opportunities which are out there.

Organizations other than CanWEA have been active, too. C/REIC, the Conservation/Renewable Energy Industry Council, developed by Jeff Passmore, was instrumental in a number of lobby efforts, and produced a masterpiece about Small Power which has set the standard by which utilities and governments in this country interpret the industry. The Small Power Producers of Alberta set precedents for all other provinces in activities such as lobbying and interventions, as well as promotion of the industry. And IPPSO, with the ongoing EAB Hearings and the recent successful conference in Toronto, is an example of how that approach can grow into a monumental and very influential success.

Individual interventions, such as the Alberta ERCB hearing in 1984 concerning Ernie Sinnott, are just another example of an industrial initiative in Canada.

But...we in Canada are sadly far behind the rest of the world in such activities, particularly those that combine the efforts of industry and government.

Activities which have occurred in Other Countries

In the US, the now famous (infamous?) tax credits of the early 1980's were the initiatives which first fuelled the industrial engine that is now a multi-million dollar industry. Despite some of the bad stories, these initiatives were a success, and it may be that none of the industry - worldwide - might have existed in its current state, were it not for these.

There have recently been a number of programs developed in Europe which were put into place at least partly as a result of industrial lobbying. European loan guarantees and assistance are just one. A number of countries provide loan guarantees for manufacturers, line of credit backing for export sales, and direct industrial assistance, targeted right at the wind industry, in order to support it and aid commercialization.

The Danish government has had in place for over one year now a warranty guarantee program, paid into by industry and government, which provides long term warranty coverage for specified Danish turbines sold into export markets.

A number of countries have established quotas for wind capacity, including Denmark, Holland and Germany. These are based not only on industrial initiatives, but for environmental and social reasons.

In many of these same countries, the pricing for power is being re-examined, and full cost pricing/accounting is being considered, and even implemented.

Many countries still provide owner grants and tax incentives to encourage private investment in wind energy and equipment. These policies all boil down to a change in national government policies, as well as in many cases utility policies, brought about by and as industrial initiatives.

Current Industrial Initiative's in Canada

There are actually a number of Industrial Initiatives ongoing in Canada at the current time, with the promotion of the wind energy industry in mind. CanWEA's government activities this year have included public comments on reports about Alberta government activities to promote the industry, and the development of a Federal Position Paper for the House of Commons Standing Committee of EMR. These activities, which help to guide and advise our governments, provide feedback and information on what is being done right, and what we feel may be off course, are important roles for CanWEA, and for our industry. As an organization which represents not only industry, but users, academics and individuals involved or interested in wind energy, CanWEA should and must continue in these activities, and in fact should step them up and be unafraid of negative comments from outside our community.

In the West, the promotion of our industry by individuals and separate firms has taken a new direction, with the establishment of the Western Wind Industry Network of Canada [WWINC], whose activities and directions specifically are to conduct regional industrial lobbying, with and for members from the four western provinces and the territories. WWINC has already been active in interventions with the Public Utilities Board in Alberta, particularly with respect to social costs of energy,is preparing to start similar work in BC, and is considering some specific actions in Saskatchewan with the new government now in place. Already, most of Alberta's industry are members, and there are members from Saskatchewan and British Columbia.

A significant initiative which is underway, though very slowly still, is the Technology Inflow Mission Concept. Work has been initiated with our firm, Industry Science and Technology, EMR, and with discussions with Alberta Energy and Environment, as well as a number of firms and individuals. The idea is simple: round up the people in Canada who need 'convincing' about our industry, take them to a place where the industry is active, working, and successful, and show them that we can have that kind of activity here, too. The targets are federal and provincial energy policy and political/technical seniors with decision-making capability, senior utility policy and engineering staff, and senior members of the financial community. The suggested location is San Gorgonio Pass. The basis is that there is no substitute for experience, and the experience of being in the middle of several thousand working turbines, with crews out there, with the manufacturing and service facilities in sight and an opportunity to directly question industry and utility experts about all or any concerns will convince even the worst doubters that this is a real technology, a real industry, and that Canada better get going, support our domestic industry, or it will just be a market for offshore firms, only.

There are certainly other initiatives current, including the Alberta SWAREI program, the BC IPP program, and the Saskpower RFP for a windfarm.

Future suggested Industrial Initiative's Activities

These are not enough. We need more 'WWINCs' in other areas. We need to support CanWEA more, involve more of the members, not just the directors - we need you to volunteer, to let us know your capabilities, and to work hard when you are asked.

We need more interventions, in more provinces. We need more lobbying to more governments, the utilities, the customers.

I think we need Joint Ventures with utilities, governments, with CEA. We need to work together with our customers, which is ultimately what the utilities are.

We need more liaisons and activity with financing groups and agencies, we need to understand them more, and we need them to think about us more.

We need to work more with the regulatory agencies: CSA, electrical protection branches, PUBs, [ERCBs], Environment/Energy, planning commissions.

There is still a lot we need to do. It is going to take energy, time and money. It is going to take dedicated people, businesses, and dedicated assistance and support from our governments. We are not yet there, but we are getting closer, to commercialization, to having a Canadian industry. But, as we get closer, there is even a higher risk that we shall not have one at all. For, as the marketplace becomes ready for us, there are players from the already well-developed markets who are prepared to compete very aggressively, and from extremely strong and well-funded positions. We must be strong, and we **must** act.

Conclusion

Industrial Initiative's are used by all commercial industrial sectors, all over the world. They are a sign of a maturing industry, and an indication of commercial activity actually proceeding.

Industrial Initiative's, started by industry, provide firm guidance and direction, as well as positive feedback, for government programs.

Industrial Initiative's, started by governments, indicate in a positive way the support and policy backing for an industrial sector, responding to the needs and requirements defined by industry.

Industrial Initiative's are becoming, and will be, an on-going way of life for our industry just as it is for many others. We must participate now, and in the future, and we must become literate, experienced, and comfortable in the role of lobbyist, as well as industrialist.

THE ENVIRONMENTAL ASSESSMENT BOARD HEARINGS

AN INVESTIGATION INTO ONTARIO HYDRO'S ELECTRIC GENERATION PLANNING PROCESS

By
Jeff Passmore
President
PASSMORE ASSOCIATES INTERNATIONAL
Ottawa/Toronto

Presented at
MONTREAL, QUEBEC
November 5, 1991

These hearings are quite complex but what I hope to be able to leave you with at the end of the day is a sense of:

- what is the purpose of the hearings
- what have we heard so far
- where are we going
- what does it all mean (assuming I know!)

In December 1989, Ontario Hydro released the Demand / Supply Plan (DSP) "Providing The Balance of Power". This is Hydro's plan to meet the electricity needs of Ontario for the period 1990 - 2014.

The current environmental assessment hearings looking into the DSP are quite unprecedented - never before has there been such scrutiny of a major North American utility. More than $25 million will be spent on intervenor funding alone and the process will take at least two years to complete.

This is a planning hearing. It is a hearing about judgement calls - judgement about such matters as:

- what will electricity demand be over the planning horizon;
- what will the environmental regulatory regime be and which technologies will be out of favour;
- what will the costs of various options be and will costs of certain "cleaner" technologies be "competitive";
- will demand management and/or non-utility generation live up to expectations in terms of delivery potential.

In the realm of wind energy, it is a judgement about what the contribution of wind energy will be to Ontario electricity supply to 2014. In the DSP, it was Hydro's judgement that the contribution would be zero. Even Hydro recognized that this was an error in judgement and during the course of the hearings released the "Alternative Energy Review" which says the contribution from wind could be between 1 and 40 MW. It is my submission that this too is an error in judgement and IPPSO and CANWEA intend to demonstrate the extent of this error in our evidence in chief.

Hydro has divided its evidence into 11 "panels" or subject areas. These are load forecasting, the existing system, avoided cost, demand management, non-utility generation, hydraulic, purchase options including transmission, fossil/alternative, nuclear, and two planning panels. The hearings began in April and we are now at the point where Hydro has finished its evidence and been cross-examined to the end of panel V.

I expect it could take us until July of 1992 to complete this part of the process (Hydro's evidence-in-chief and cross-examination thereupon).

Once Hydro has finished putting forward its case, intervenors will present their evidence. IPPSO and CANWEA (which is a member of the IPPSO coalition) were well funded ($2.7 million) and as such are able to be well prepared both for cross examination and their own evidence. The Coalition of Environmental Groups (Greenpeace, Friends of the Earth, etc.) were also well funded - $2.8 million, as were the Municipal Electric Association and a number of native groups. (I will say more about the native groups later).

There have been major changes to the DSP as a result of this process. This "moving target" has been a bit of a problem, but it is the process of the hearings themselves that keeps Hydro on its toes. Recent changes include:

- another 1000 MWs of NUGs for a total of 3100MW
- fuel switching from electric homes to natural gas
- removal of the Moose River hydraulic sites (1469 MW)
- load not materializing as forecast
- 2600 MW surplus by the year 2000
- the need date for a new large central facility has been pushed back to 2006? 2008? 2010?

Hydro is now "rebalancing" the Balance of Power and will release this new document in January 1992.

Where is IPPSO going with its case?

There are two thrusts:
- what is the value of power in Ontario
- what is the extent of the NUG resource

With respect to the value of power we can look at economic value which would include such variables as capital cost, operations & maintenance costs, life expectancy, capacity factor, etc.; and we can look at non-economic values such as social costs, the impacts of emissions, health problems, etc. The latter values (more commonly thought of as externalities) will be looked at by other intervenors such as the environmental groups. IPPSO will concentrate on economic values.

With respect to the extent of the resource, we are conducting a number of resources assessments for technologies such as cogeneration, combined cycle, small hydro, wind, wood waste, EFW and so on. We look first at technical potential and then, using a series of assumptions, we calculate the economic, financial and market potential of the given resource base. In the case of wind, the technical potential in Ontario is in the thousands of MWs. We are just in the process of determining the market potential.

What does this all mean? Given the changes to the original DSP as enumerated above (more NUGs, more DSM, surplus generation, delayed need date for large central plant) one might well ask why we are all here. Are we conducting these hearings just to determine the future of the Manitoba purchase and a handful of hydraulic sites?

Since we don't need a large central plant until 2008 (or so it may seem) why don't we all go away and come back in 1996 after we've had a chance to determine the impact of DSM and NUG initiatives?

Of course, the hearings themselves are helping advance the cause of DSM because Hydro has to be seen to be doing something and without the Board's and the public's watchful eye, the changes we have seen thus far would not have happened. Nevertheless it has been said that Hydro is one of the few (if not the only) utility in North America that is currently planning to build something (a nuclear plant) in the year 2008. The Board could tell Hydro to be very aggressive on DSM and NUGs and to report back in four years on its progress and until that time they have approval for nothing else. (Of course this may not be practical as the process is well along.)

Since the need for a construction project has not been demonstrated (we seem to be going in the opposite direction), why do we need to go through the major supply options at this time? Is this the way to do planning? Is Hydro really as bad at this as the hearings have demonstrated to date? It is clear that Hydro is not PG&E (Pacific Gas & Electric). It is clear that Hydro (as a corporation) is a long way from enlightenment. It is clear that despite Hydro's claim that the DSP is robust and flexible, the internal need for a new large construction project does not fall within that flexibility. This part of Hydro's corporate culture is what needs to change to bring Hydro into the 1980's (let's worry about the 1990's later).

It could very well be that there is no future for nuclear power in Ontario. We have to accept that possibility and get on with pursuing the options that reduce planning risk - short lead time options like DSM which OME studies tell us can offer 9000 MW of capacity equivalent at 5 cents/kWh or less.

Given the potential for DSM in Ontario we have to accept not only that we don't need new large central plant, but that we may not need much NUG - including wind power. With DSM as the first priority, NUG would only be relied upon as a fill-in technology.

I mentioned the involvement of native peoples in the hearings. Several groups are active including the Moose River/James Bay Coalition, the Nipigon Aboriginal Peoples' Alliance, the North Shore Tribal Council, the Ontario Metis and Aboriginal Association, and the Nishnawbe-Aski Nation. Never before have the natives been so well represented and I don't think the Board or any other party really knows how the native perspective will be properly integrated into the final hearing decision. But the native view must be respected and in this context I want to convey some of the messages that were delivered to the Board at public meetings held September 2 - 6 at Moosenee and Moose River and attended by 300 and 400 people respectively.

- "Toronto should use its garbage to generate electricity."
- "Before the dam at Otter Rapids was built, there were lots of fish, raspberries, etc.; afterwards, the trees were all flooded, there were no fish and no berries."

- "Indian Lake Reservior project is destroying northern Manitoba, and will go on to destroy the rest of it. Ontario Hydro should dam the Humber and the Don. We don't need the energy, nor will we need it in the future. The rivers are already gasping for water. Greedy people will snuff them out."
- "As a coastal resident, from the east side of James Bay, I have heard the stories of women there. Burial grounds and hunting grounds are under water; fish and wildfowl cannot be eaten; a way of life has been destroyed."
- There used to be commercial fishing on rivers such as the Mattagami before the dams were built. Now the water is polluted, and the forest has been clear cut."
- "Canada is treating its northern lands like the South Americans are treating the rain forests. We are inefficient; we must learn to conserve."
- "There is no business sense to the proposals as they stand. Perhaps Hydro is proposing 16 sites to get approval for four."
- "Can we sue Hydro?"
- "Silting problems in the river will destroy the barge and boating business."

It could very well be that for environmental reasons alone (putting aside economic ones) there will be no new large hydraulic development in Ontario. With no new nuclear and possibly no new fossil, where does that leave us? We have heard from PG&E that in the context of electric power planning we must examine our ethical standards. I say we must remember that it is the ratepayers - you and I - that cause the environmental externalities that accompany the various electric generation choices. As such, it is the ratepayers that must pay. If costs of clean energy technologies come down, perhaps then we can have a clean environment and abundant cheap power. But even if costs don't come down we must address energy policy in the context of its linkages to the environment and the environmental externalities caused by conventional fuel burn. To date, by excluding environmental impacts, we are simply kidding ourselves that electricity is cheap.

That in part, is what the DSP hearings should be about. As Dr. Olav Hohmeyer of Germany points out, by not including environmental externalities in the cost of conventional energy options to date, we have missed the optimal period for introducing wind energy (for example) in Germany by about 10 years. That is, from a total societal perspective and including all externalities, wind energy would have been cost-competitive with conventional power in Germany in the late 1970's to mid '80's. By not including externalities, wind will not likely reach its full market penetration until 2000. In the meantime, a great deal of environmental damage will have resulted from conventional fuel consumption.

As ratepayers, we must understand these issues. We must understand the impact of our decisions and we must integrate these into the planning process. If the results of the DSP hearings do not achieve this understanding, it will not, in my estimation, have met its responsibilities.

I close with another quote from the native meetings held in the Moose River area:
"Compensation may be appropriate for environmental and economic consequences, but there is no compensation for breaking a man's spirit."

TECHNICAL AND ECONOMIC POTENTIAL FOR WIND ENERGY DEVELOPMENT IN ONTARIO

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INTRODUCTION

Passmore Associates International has requested that R. Lynette & Associates (RLA) estimate the technical potential for wind energy development in the province of Ontario in order to support testimony for public hearings on Ontario Hydro's 25 Year Demand/Supply Plan. The purpose of this report is to provide the estimates and supporting information on the status and reliability of wind energy technology and its application in Ontario. The report presents the technical potential of wind energy in terms of the number and nature of sites suitable for wind energy development in Ontario and the capital costs and energy production estimates associated with these sites.

APPROACH

RLA reviewed the available information and developed a preliminary estimate of the technical potential for wind energy in the province of Ontario. The approach was to estimate the number and size of sites that have potential for wind development based on their terrain and vegetation characteristics, location in an area that appears to have adequate wind resources, and proximity to transmission and load centers.

The wind resource characteristics were based on a database of wind speed and direction information for 85 anemometers spread throughout Ontario from the Canadian Climate Centre archive at the Atmospheric Environment Service. Geographical data were obtained from detailed maps and a database of terrain information that consisted of digitized elevation and land surface codes from the Communications Research Centre in Canada. The electrical infrastructure information was obtained from maps prepared for the Ontario Hydro Demand/Supply Plan.

As a basis for establishing case studies, five categories of wind speeds were established to reflect the varying levels of wind energy feasibility. These levels, and the number of anemometer sites in each level are presented in Table S-1. Case studies were further defined by project sizes. Project sizes of 5 MW, 20 MW, 50 MW, and 100 MW were evaluated. In addition, two technology levels were considered: one representative of the technology currently available and one representative of future technology that is presently under development.

TABLE S-1. WIND SPEED CATEGORIES
(Data Adjusted to 30 Meters)

CATEGORY	WIND SPEED (M/S)	NUMBER OF ANEMOMETERS	DESCRIPTION
1	0 - 4	20	Not feasible for wind energy development
2	4 - 5	27	Poor wind energy potential
3	5 - 6	29	Limited wind energy potential
4	6 - 7	9	Adequate wind energy potential
5	7 +	2	Good wind energy potential

FINDINGS

The region of Northern Ontario generally has low wind speeds and poor wind energy potential. The few spots that appear to have some potential are remote and far from any load centers or transmission lines.

The region identified as coastal Southern Ontario has been identified as the most promising area for wind energy in Ontario. This area consists of the coastal areas along the eastern shores of Lake Superior, Lake Huron, and Georgian Bay and the northern shores of Lake Erie, Lake Ontario, and the Saint Lawrence River. It is likely that the best wind sites are close to the coast on the highest, most exposed hills.

Table S-2 shows the estimated number of developable projects in each wind speed category for each project size. The numbers in Table S-2 represent only 20% of the bare land in each wind speed category because it is not reasonable to consider that all bare land in each wind speed category could be developed into wind power stations.

TABLE S-2. ESTIMATED DISTRIBUTION OF POTENTIAL PROJECTS IN SOUTHERN ONTARIO

Wind Speed (m/s)	5MW Project	20MW Project	50MW Project	100MW Project
4 - 5	43%	19%	8%	5%
5 - 6	12%	5%	5%	2%
6 - 7	2%	<1%	<1%	<1%
7 +	<1%	<1%	<1%	<1%

Cost estimates were developed for the technology-specific economic factors that include the capital cost of the equipment and construction and the operation and maintenance costs. Capital cost estimates were based on quotes from equipment manufacturers and experience with recently installed wind power stations. Operation and maintenance costs were based on actual field experience and discussions with operators, manufacturers, and equipment suppliers. Table S-3 summarizes the cost and performance estimates for current technology for each of the case studies. Table S-4 summarizes the cost and performance estimates for future technology for each of the case studies.

TABLE S-3. SUMMARY OF TECHNOLOGY-SPECIFIC ECONOMIC FACTORS -- CURRENT TECHNOLOGY

CURRENT TECHNOLOGY (Canadian dollars)	-- WIND REGIME: 4-5 M/S --				-- WIND REGIME: 5-6 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$1,120,400	$1,120,400	$1,073,400	$1,073,400	$1,120,400	$1,120,400	$1,073,400	$1,073,400
Balance-of-Station	$295,341	$254,341	$251,588	$248,621	$295,341	$254,341	$251,588	$248,621
TOTAL CAPITAL COSTS ($/MW)	$1,415,741	$1,374,741	$1,324,988	$1,322,021	$1,415,741	$1,374,741	$1,324,988	$1,322,021
ANNUAL O&M COSTS ($/MW)	$11,700	$11,989	$11,973	$11,948	$16,737	$17,275	$17,244	$17,198
NET ANNUAL ENERGY (MWH/MW)	584	613	611	609	1,085	1,139	1,136	1,131
CAPACITY FACTOR	6.67%	7.00%	6.98%	6.95%	12.39%	13.00%	12.96%	12.91%

CURRENT TECHNOLOGY (Canadian dollars)	-- WIND REGIME: 6-7 M/S --				-- WIND REGIME: > 7 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$1,120,400	$1,120,400	$1,073,400	$1,073,400	$1,120,400	$1,120,400	$1,073,400	$1,073,400
Balance-of-Station	$295,341	$254,341	$251,588	$248,621	$295,341	$254,341	$251,588	$248,621
TOTAL CAPITAL COSTS ($/MW)	$1,415,741	$1,374,741	$1,324,988	$1,322,021	$1,415,741	$1,374,741	$1,324,988	$1,322,021
ANNUAL O&M COSTS ($/MW)	$22,298	$23,110	$23,063	$22,994	$27,849	$28,935	$28,873	$28,780
NET ANNUAL ENERGY (MWH/MW)	1,638	1,719	1,714	1,708	2,190	2,298	2,292	2,283
CAPACITY FACTOR	18.70%	19.62%	19.57%	19.49%	25.00%	26.24%	26.17%	26.06%

TABLE S-4. SUMMARY OF TECHNOLOGY-SPECIFIC ECONOMIC FACTORS -- FUTURE TECHNOLOGY

FUTURE TECHNOLOGY (Canadian dollars)	-- WIND REGIME: 4-5 M/S --				-- WIND REGIME: 5-6 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909
Balance-of-Station	$280,814	$239,982	$235,177	$232,213	$280,814	$239,982	$235,177	$232,213
TOTAL CAPITAL COSTS ($/MW)	$955,723	$914,891	$910,086	$907,123	$955,723	$914,891	$910,086	$907,123
ANNUAL O&M COSTS ($/MW)	$11,282	$11,584	$11,567	$11,541	$16,319	$16,870	$16,838	$16,791
NET ANNUAL ENERGY (MWH/MW)	610	640	638	636	1,111	1,166	1,162	1,158
CAPACITY FACTOR	6.96%	7.30%	7.28%	7.26%	12.68%	13.31%	13.27%	13.22%

FUTURE TECHNOLOGY (Canadian dollars)	-- WIND REGIME: 6-7 M/S --				-- WIND REGIME: > 7 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909
Balance-of-Station	$280,814	$239,982	$235,177	$232,213	$280,814	$239,982	$235,177	$232,213
TOTAL CAPITAL COSTS ($/MW)	$955,723	$914,891	$910,086	$907,123	$955,723	$914,891	$910,086	$907,123
ANNUAL O&M COSTS ($/MW)	$22,020	$22,852	$22,804	$22,733	$28,580	$29,735	$29,669	$29,570
NET ANNUAL ENERGY (MWH/MW)	1,678	1,760	1,756	1,749	2,330	2,445	2,439	2,429
CAPACITY FACTOR	19.15%	20.10%	20.04%	19.96%	26.60%	27.91%	27.84%	27.72%

ONTARIO WIND ENERGY POTENTIAL

WIND RESOURCE

- Wind information
- Topography and land use information
- Available sites
- Limits on resource potential

TECHNOLOGY

- Energy production estimates
- Present and future technology
- Limits on technological potential

ECONOMIC POTENTIAL

- Capital costs
- O&M costs
- Limits on economic potential

WIND RESOURCE

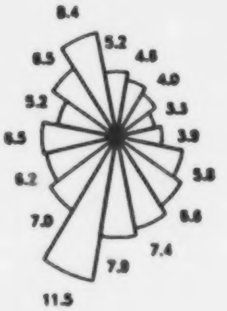
WIND INFORMATION

- wind speed frequency distributions at 85 sites derived from climate archives of the Canadian Climate Centre of the Atmospheric Environment Service and Canadian Climate Normals
- longest records 1953 - 1988 (35 years)
- high quality data, high data recovery rate
- vertical height adjustment using

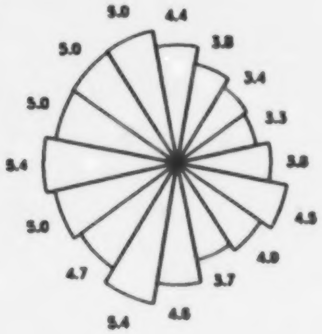
$$\frac{V_{30}}{V_{anm}} = \left(\frac{30}{z_{anm}}\right)^{a}$$

- no topographic or surface roughness adjustment

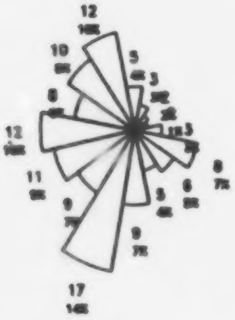
FREQUENCY (%)

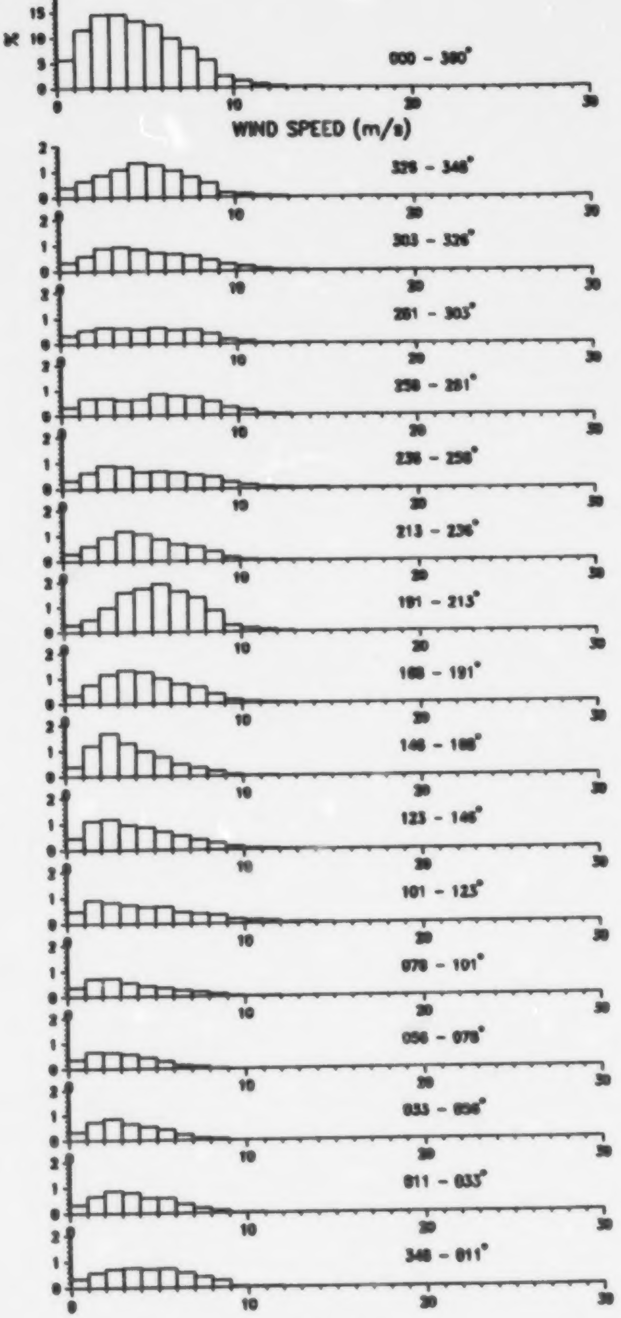


AVERAGE SPEED (m/s)
4.6m/s



ENERGY DENSITY (W/m**2)
122.W/m**2

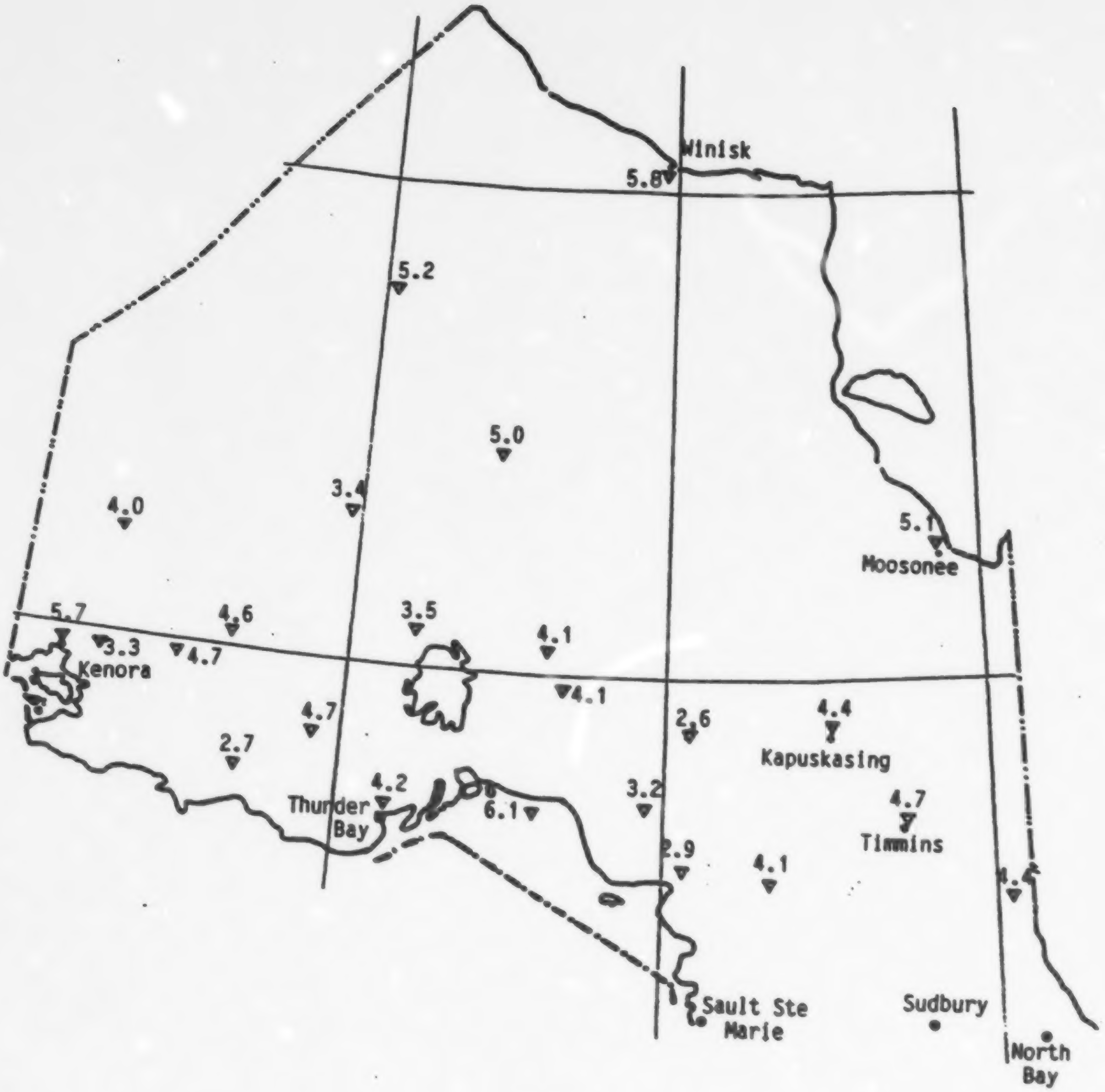




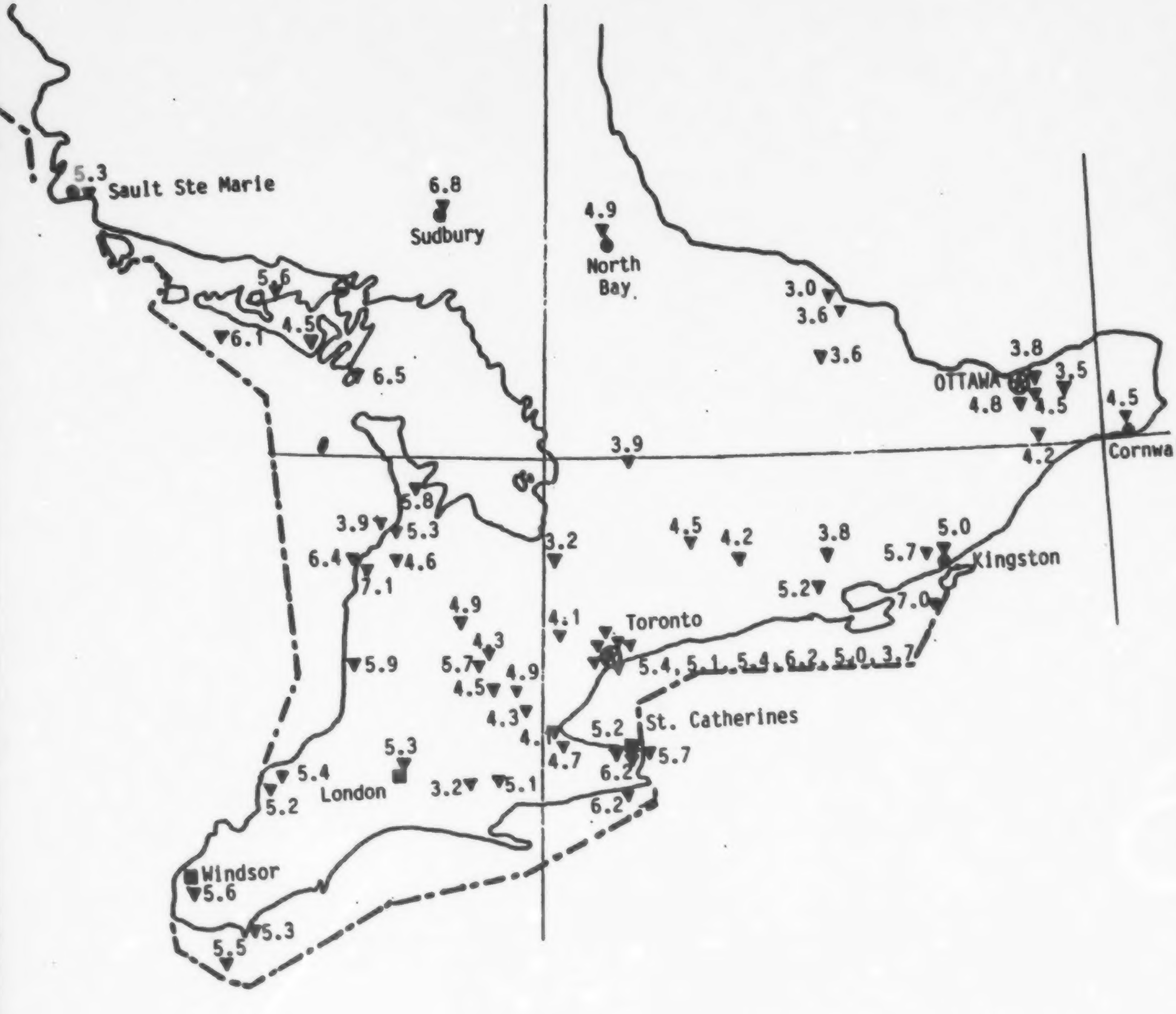
Goderich Municipal A (GoderchA, 0)
Lat. 43.77 Long. 81.70 Elev. 213.m
At 10.4m a.g.l.

1953J001 0000 - 1988J366 2359

Synoptic hourly data from AES archive


Winisk
5.8
5.2
5.0
4.0
3.4
5.1
Moosonee
5.7
4.6
3.5
4.1
3.3
4.7
Kenora
4.1
4.7
2.6
4.4
Kapuskasing
2.7
4.2
Thunder Bay
6.1
3.2
4.7
Timmins
2.9
4.1
4.4
Sault Ste Marie
Sudbury
North Bay

AVERAGE ANNUAL WIND SPEED (m/s)
NORTHERN ONTARIO
(Adjusted to 30m a.g.l.)


5.3
Sault Ste Marie
6.8
Sudbury
4.9
North Bay
5.6
4.5
6.1
6.5
3.0
3.6
3.6
3.8
OTTAWA
3.5
4.8
4.5
4.5
4.2
Cornwall
3.9
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5.3
6.4
4.6
7.1
3.2
4.5
4.2
3.8
5.0
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Kingston
5.2
7.0
4.9
4.3
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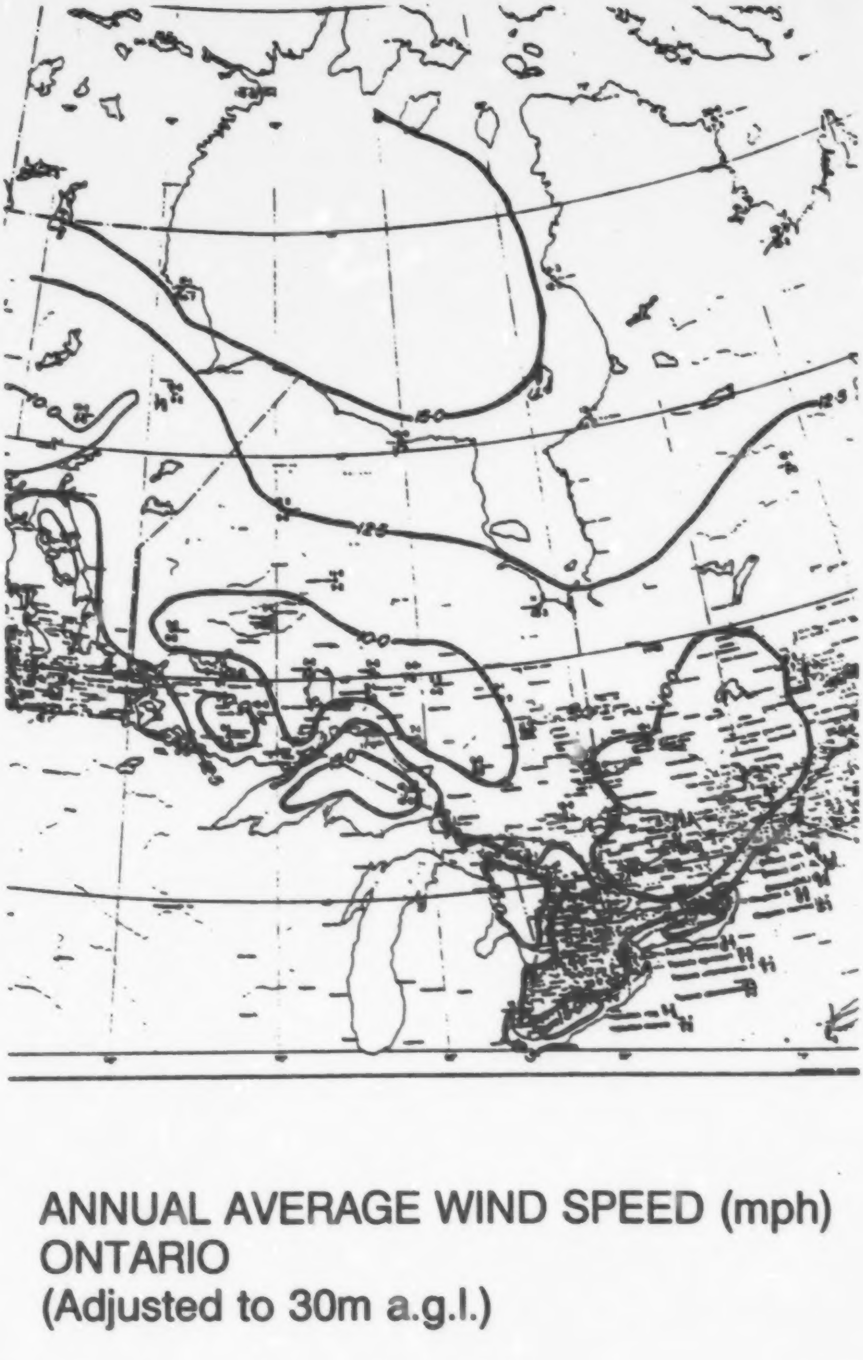
Toronto
5.9
5.7
4.9
5.4, 5.1, 5.4, 6.2, 5.0, 3.7
4.5
4.3
St. Catherines
5.2
4.1
4.7
5.7
6.2
5.3
5.4
5.2
London
3.2
5.1
6.2
Windsor
5.6
5.3
5.5

AVERAGE ANNUAL WIND SPEED (m/s)
SOUTHERN ONTARIO
(Adjusted to 30m a.g.l.)


150
125
125
100
100

ANNUAL AVERAGE WIND SPEED (mph)
ONTARIO
(Adjusted to 30m a.g.l.)

ONTARIO WIND ENERGY POTENTIAL

WIND SPEED CATEGORIES
(adjusted to 30m)

Category	Wind Speed (m/s)	No. of Sites	Description
1	0 - 4	20	Not feasible for wind energy
2	4 - 5	27	Poor wind energy potential
3	5 - 6	29	Limited wind energy pot.
4	6 - 7	9	Adequate wind energy pot.
5	7 +	2	Good wind energy pot.

TERRAIN INFORMATION

- derived from C.R.C. (Communications Research Centre) topographic data base

- elevation and land surface codes on 0.5 x 0.5 km centres south of 49°

LAND SURFACE CODES

Code	Description
0	Surface type unknown
1	Tree cover
2	Bare ground (no trees)
3	Fresh water (lakes and rivers)
4	Suburban (most buildings < 3 stories)
5	Marsh
6	Seawater
7	Urban Core (high density, tall buildings)

BARE LAND AND WIND REGIMES

ESTIMATED BARE AND DEVELOPABLE LAND BY WIND CATEGORY
(Ontario, South of 49°)

Wind Speed (m/s)	Bare Land %	Bare Land (km^2)	Developable Bare Land (km^2)
0 - 4	52%	31,575	6,315
4 - 5	35%	21,089	4,218
5 - 6	11%	6,675	1,335
6 - 7	1%	777	155
7 +	<1%	154	31
	100%	60,270	12,054

- MAJOR ASSUMPTION • 20% of bare land is developable

CASE STUDIES

- project sizes of 5, 20, 50, 100MW with turbine spacing of 10 rotor diameters (260m) require 1.0, 4.5, 12.5 and 25.0 km^2 contiguous, developable bare land respectively

ESTIMATED NUMBER OF POTENTIAL PROJECTS
(Ontario, South of 49°)

Wind Speed (m/s)	5MW Project	20MW Project	50MW Project	100MW Project
4 - 5	43%	19%	8%	5%
5 - 6	12%	5%	5%	2%
6 - 7	2%	<1%	<1%	<1%
7 +	<1%	<1%	<1%	<1%

LIMITS ON RESOURCE

- wind resource can fluctuate slightly (10% annually) but unlikely to change significantly in foreseeable future

- available developable land may decrease through competition from other users (However, marine development may add to the resource.)

- marine projects

TECHNOLOGY

ENERGY PRODUCTION ESTIMATES

- fit Weibull distribution (k=2) for Ontario wind resource
- use known power curves from commercially available wind turbines - "Present Technology"
- use tentative power curves from two turbines currently under development and available in three to five years - "Future Technology"
- assume following losses (% of production):

Line losses	3%
Blade soiling	5%
Turbulence and control losses	5%
Downtime	10% (5MW projects) 5% (20, 50, 100MW projects)
Array losses	6.0% (5MW) 7.5% (20MW) 7.7% (50MW) 8.0% (100MW)

PRESENT TURBINE TECHNOLOGY

- 100kW
- upwind
- rigid rotor
- 3 fibreglass blades
- fixed pitch
- fixed rotation speed
- active yaw system

FUTURE TURBINE TECHNOLOGY

- convergence to optimum turbine size of 200-500kW

- better understanding of wind loads
- improved design codes
- inexpensive access to finite element modelling
    - ▸ lighter turbines
    - ▸ reduced capital costs
    - ▸ larger rotors

- advanced airfoils by SERI
- 15% larger rotors
    - ▸ higher production in low wind speed
    - ▸ lower sensitivity to soiling
    - ▸ 25-30% more energy production

- variable speed operation
    - ▸ 8-20% increase in efficiency with lower wind loads
    - ▸ unity power factor
    - ▸ reduced harmonics

- advanced materials
    - ▸ lighter, stronger blades

- adaptive control systems

- taller towers

ONTARIO WIND ENERGY POTENTIAL

AVERAGE ANNUAL TURBINE PERFORMANCE
(Southern Ontario Wind Distribution)

Wind Speed (m/s)	Average (kWh/kW)	Average (kWh/m^2)
Current Technology		
4.5	822.8	326.8
5.5	1,528.5	609.8
6.5	2,307.4	923.3
7.5	3,085.1	1,237.1
Future Technology		
4.5	858.8	340.6
5.5	1,564.5	628.0
6.5	2,363.0	954.4
7.5	3,282.0	1,324.8

NET ENERGY PRODUCTION FOR EACH CASE STUDY

	NET PROJECT ENERGY (kWh)			
	-- Project Size --			
Wind Speed	5 MW	20 MW	50 MW	100 MW
CURRENT TECHNOLOGY				
4-5 M/S	2,921,112	12,260,443	30,568,822	60,890,789
5-6 M/S	5,426,097	22,774,323	56,782,960	113,107,376
6-7 M/S	8,191,436	34,380,958	85,721,650	170,751,066
> 7 M/S	10,952,158	45,968,214	114,612,024	228,298,514
FUTURE TECHNOLOGY				
4-5 M/S	3,048,874	12,796,681	31,905,819	63,553,986
5-6 M/S	5,553,973	23,311,043	58,121,157	115,772,964
6-7 M/S	8,388,798	35,209,322	87,787,000	174,865,088
> 7 M/S	11,650,990	48,901,338	121,925,148	242,865,705

LIMITS ON TECHNOLOGICAL POTENTIAL

- match between wind power station output and utility energy demand
- grid interconnection and transmission
- penetration of wind energy into total supply
- low temperature operation
    - icing
    - maintenance
- project siting issues

ECONOMICS

- capital cost of equipment and construction
  - related to project size only

- operation and maintenance (O&M) costs
  - related to project size and wind speed category

CAPITAL COSTS FOR WIND TURBINES

FOB WIND TURBINE COSTS

TURBINE	RATING (KW)	SINGLE UNIT COST (CDN$)	SINGLE UNIT $/kW	MULTIPLE UNIT COST (CDN$)	MULTIPLE UNIT $/kW
Turbine A	250			$272,239	$1,089
Turbine B	275			$272,239	$990
Turbine C	150	$170,149	$1,134	$165,896	$1,106
Turbine D	300	$306,269	$1,021	$280,746	$936
Turbine E	350	$442,388	$1,264	$416,866	$1,191
Turbine F	225	$252,161	$1,121	$241,612	$1,074
Turbine G	400	$440,006	$1,100	$421,970	$1,055
Turbine H	250	$228,851	$915	$203,328	$813
Turbine I	150	$221,194	$1,475	$210,985	$1,407
Turbine J	250	$227,149	$909	$216,940	$868
Turbine K	150			$193,119	$1,287
Turbine L	300			$327,537	$1,092
Turbine M	450			$467,060	$1,038
Turbine N	250	$285,000	$1,140		
Turbine O	100	$95,760	$958	$85,500	$855
AVERAGE			$1,104		$1,057
MAXIMUM			$1,475		$1,407
MINIMUM			$909		$813

- future technology - $660/kW
- shipping - $4100 regardless of origin

BALANCE OF STATION COSTS FOR EACH CASE STUDY

CURRENT TECHNOLOGY	-- PROJECT CAPACITY --			
	5 MW	20 MW	50 MW	100 MW
Surveying, roads, grading, and fences	$68,400	$273,600	$684,000	$1,368,000
Collection system and transmission lines	$456,000	$1,824,000	$4,560,000	$9,120,000
Substations	$228,000	$912,000	$2,280,000	$4,560,000
Turbine foundations, installation, and checkout	$228,000	$878,400	$2,196,000	$4,392,000
Controls and monitoring equipment	$136,800	$307,760	$649,800	$1,219,600
Maintenance facilities, equipment, and initial spare parts	$93,060	$315,280	$994,400	$1,937,200
Insurance, legal fees, and miscellaneous costs	$266,443	$575,779	$1,215,208	$2,265,302
Total Balance-of-Station	$1,476,703	$5,086,819	$12,579,408	$24,862,102

FUTURE TECHNOLOGY	-- PROJECT CAPACITY --			
	5 MW	20 MW	50 MW	100 MW
Surveying, roads, grading, and fences	$64,255	$257,018	$642,545	$1,285,091
Collection system and transmission lines	$456,000	$1,824,000	$4,560,000	$9,120,000
Substations	$228,000	$912,000	$2,280,000	$4,560,000
Turbine foundations, installation, and checkout	$189,655	$728,073	$1,820,182	$3,640,364
Controls and monitoring equipment	$131,618	$287,055	$598,000	$1,116,000
Maintenance facilities, equipment, and initial spare parts	$73,636	$237,600	$705,455	$1,359,637
Insurance, legal fees, and miscellaneous costs	$260,908	$553,892	$1,152,671	$2,140,257
Total Balance-of-Station	$1,404,072	$4,799,638	$11,758,853	$23,221,349

OPERATION AND MAINTENANCE COSTS

- because maintenance facilities, initial spare parts and equipment are included in the balance-of-station costs, the majority of O&M costs vary with energy production - variable cost

- annual O&M costs have decreased with experience in the wind industry from $0.03/kWh (1981) to $0.014/kWh (1987) to $0.009-0.013/kWh (presently)

O&M BREAKDOWN

- DIRECT COSTS

  - LABOUR (44%)
    - maintenance (scheduled and unscheduled)
    - operation and monitoring of turbines

  - PARTS (35%)
    - components that are replaced

- INDIRECT COSTS

  - OPERATIONS (12%)
    - maintenance of the availability of turbines
    - administration of daily activities
    - monitoring energy production
      - monitoring performance
      - controlling operation
      - dispatching maintenance crews

  - EQUIPMENT (5%)
    - trucks for maintenance personnel
    - crane rental
    - shop equipment
    - spare parts carrying costs (15%)

  - FACILITIES (4%)
    - upkeep and operation of on-site facilities

ANNUAL O&M COSTS
(per Turbine)

	CURRENT	FUTURE
GENERAL O&M COSTS		
Parts	$4,646	$4,247
Maintenance hours		
Scheduled	17h	17h
Unscheduled	40h	35h
Administrative hours	12h	12h
Labour Rate	$34.20	$34.00
TOTAL	$7,005	$6,435
FIXED PORTION	$1,456	$1,416
VARIABLE PORTION	$5,549	$5,019
VARIABLE RATE ($/kWh)	0.0101	0.0074

Note: variable rate calculation assumes 28% capacity factor

O&M COSTS FOR EACH CASE STUDY -- CURRENT TECHNOLOGY

Fixed O&M (per WT) $1,456
Number of Turbines 20
Variable O&M ($/kWh) $0.0101

5 MW PROJECT - CURRENT TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	2,921,112	$29,127	$29,371	$58,498
5-6 m/s	5,426,097	$29,127	$54,557	$83,684
6-7 m/s	8,191,436	$29,127	$82,362	$111,489
>7 m/s	10,952,158	$29,127	$110,120	$139,247

Fixed O&M (per WT) $1,456
Number of Turbines 80
Variable O&M ($/kWh) $0.0101

20 MW PROJECT - CURRENT TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	12,260,443	$116,508	$123,274	$239,782
5-6 m/s	22,774,323	$116,508	$228,987	$345,495
6-7 m/s	34,380,958	$116,508	$345,688	$462,196
>7 m/s	45,968,214	$116,508	$462,193	$578,701

Fixed O&M (per WT) $1,456
Number of Turbines 200
Variable O&M ($/kWh) $0.0101

50 MW PROJECT - CURRENT TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	30,568,822	$291,270	$307,358	$598,628
5-6 m/s	56,782,960	$291,270	$570,932	$862,202
6-7 m/s	85,721,650	$291,270	$861,900	$1,153,170
>7 m/s	114,612,024	$291,270	$1,152,382	$1,443,652

Fixed O&M (per WT) $1,456
Number of Turbines 400
Variable O&M ($/kWh) $0.0101

100 MW PROJECT - CURRENT TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	60,890,789	$582,540	$612,234	$1,194,774
5-6 m/s	113,107,376	$582,540	$1,137,253	$1,719,793
6-7 m/s	170,751,066	$582,540	$1,716,839	$2,299,379
>7 m/s	228,298,514	$582,540	$2,295,457	$2,877,997

O&M COSTS FOR EACH CASE STUDY -- FUTURE TECHNOLOGY

Fixed O&M (per WT) $1,416
Number of Turbines 18
Variable O&M ($/kWh) $0.0074

5 MW PROJECT - FUTUTRE TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	3,048,874	$25,754	$30,655	$56,409
5-6 m/s	5,553,973	$25,754	$55,843	$81,597
6-7 m/s	8,388,798	$25,754	$84,346	$110,100
>7 m/s	11,650,990	$25,754	$117,146	$142,900

Fixed O&M (per WT) $1,416
Number of Turbines 73
Variable O&M ($/kWh) $0.0074

20 MW PROJECT - FUTUTRE TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	12,796,681	$103,015	$128,666	$231,680
5-6 m/s	23,311,043	$103,015	$234,384	$337,398
6-7 m/s	35,209,322	$103,015	$354,017	$457,031
>7 m/s	48,901,338	$103,015	$491,685	$594,699

Fixed O&M (per WT) $1,416
Number of Turbines 182
Variable O&M ($/kWh) $0.0074

50 MW PROJECT - FUTUTRE TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	31,905,819	$257,536	$320,801	$578,338
5-6 m/s	58,121,157	$257,536	$584,387	$841,923
6-7 m/s	87,787,000	$257,536	$882,666	$1,140,202
>7 m/s	121,925,148	$257,536	$1,225,912	$1,483,449

Fixed O&M (per WT) $1,416
Number of Turbines 364
Variable O&M ($/kWh) $0.0074

100 MW PROJECT - FUTUTRE TECHNOLOGY

Wind Regime	Annual Net kWh	Fixed O&M	Variable O&M	Total Annual O&M
4-5 m/s	63,553,986	$515,073	$639,012	$1,154,085
5-6 m/s	115,772,964	$515,073	$1,164,054	$1,679,127
6-7 m/s	174,865,088	$515,073	$1,758,204	$2,273,277
>7 m/s	242,865,705	$515,073	$2,441,925	$2,956,998

SUMMARY OF TECHNOLOGY-SPECIFIC ECONOMIC FACTORS -- CURRENT TECHNOLOGY

CURRENT TECHNOLOGY	-- WIND REGIME: 4-5 M/S --				-- WIND REGIME: 5-6 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$1,120,400	$1,120,400	$1,073,400	$1,073,400	$1,120,400	$1,120,400	$1,073,400	$1,073,400
Balance-of-Station	$295,341	$254,341	$251,588	$248,621	$295,341	$254,341	$251,588	$248,621
TOTAL CAPITAL COSTS ($/MW)	$1,415,741	$1,374,741	$1,324,988	$1,322,021	$1,415,741	$1,374,741	$1,324,988	$1,322,021
ANNUAL O&M COSTS ($/MW)	$11,700	$11,989	$11,973	$11,948	$16,737	$17,275	$17,244	$17,198
NET ANNUAL ENERGY (MWH/MW)	584	613	611	609	1,085	1,139	1,136	1,131
CAPACITY FACTOR	6.67%	7.00%	6.98%	6.95%	12.39%	13.00%	12.96%	12.91%

CURRENT TECHNOLOGY	-- WIND REGIME: 6-7 M/S --				-- WIND REGIME: > 7 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$1,120,400	$1,120,400	$1,073,400	$1,073,400	$1,120,400	$1,120,400	$1,073,400	$1,073,400
Balance-of-Station	$295,341	$254,341	$251,588	$248,621	$295,341	$254,341	$251,588	$248,621
TOTAL CAPITAL COSTS ($/MW)	$1,415,741	$1,374,741	$1,324,988	$1,322,021	$1,415,741	$1,374,741	$1,324,988	$1,322,021
ANNUAL O&M COSTS ($/MW)	$22,298	$23,110	$23,063	$22,994	$27,849	$28,935	$28,873	$28,780
NET ANNUAL ENERGY (MWH/MW)	1,638	1,719	1,714	1,708	2,190	2,298	2,292	2,283
CAPACITY FACTOR	18.70%	19.62%	19.57%	19.49%	25.00%	26.24%	26.17%	26.06%

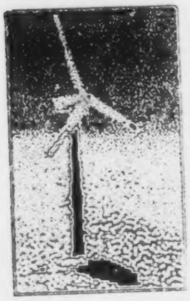
SUMMARY OF TECHNOLOGY-SPECIFIC ECONOMIC FACTORS -- FUTURE TECHNOLOGY

FUTURE TECHNOLOGY	-- WIND REGIME: 4-5 M/S --				-- WIND REGIME: 5-6 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909
Balance-of-Station	$280,814	$239,982	$235,177	$232,213	$280,814	$239,982	$235,177	$232,213
TOTAL CAPITAL COSTS ($/MW)	$955,723	$914,891	$910,086	$907,123	$955,723	$914,891	$910,086	$907,123
ANNUAL O&M COSTS ($/MW)	$11,282	$11,584	$11,567	$11,541	$16,319	$16,870	$16,838	$16,791
NET ANNUAL ENERGY (MWH/MW)	610	640	638	636	1,111	1,166	1,162	1,158
CAPACITY FACTOR	6.96%	7.30%	7.28%	7.26%	12.68%	13.31%	13.27%	13.22%

FUTURE TECHNOLOGY	-- WIND REGIME: 6-7 M/S --				-- WIND REGIME: > 7 M/S --			
	-- Project Capacity --				-- Project Capacity --			
	5 MW	20 MW	50 MW	100 MW	5 MW	20 MW	50 MW	100 MW
CAPITAL COSTS ($/MW)								
Wind Turbine Costs	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909	$674,909
Balance-of-Station	$280,814	$239,982	$235,177	$232,213	$280,814	$239,982	$235,177	$232,213
TOTAL CAPITAL COSTS ($/MW)	$955,723	$914,891	$910,086	$907,123	$955,723	$914,891	$910,086	$907,123
ANNUAL O&M COSTS ($/MW)	$22,020	$22,852	$22,804	$22,733	$28,580	$29,735	$29,669	$29,570
NET ANNUAL ENERGY (MWH/MW)	1,678	1,760	1,756	1,749	2,330	2,445	2,439	2,429
CAPACITY FACTOR	19.15%	20.10%	20.04%	19.96%	26.60%	27.91%	27.84%	27.72%

LIMITS ON ECONOMIC POTENTIAL

- power purchase price available from utility
    - "avoided cost" or other
- should wind-generated power receive capacity credits?
- possibility of penalties for fossil-fuel generation
- availability of equipment and trained personnel
- availability of investment capital - Is wind risky?



GOVERNMENT PROGRAMS

Efficiency and Alternative Energy Technology Branch

CANMET

CANADIAN WIND ENERGY R&D PROGRAM 1991/92

BY

RAJ RANGI

ALTERNATIVE ENERGY DIVISION

ENERGY MINES & RESOURCES, OTTAWA

INTRODUCTION

The Federal Government started to fund Energy R&D through the Panel of Energy R&D (PERD) in 1978. From 1978 to 1985 the mandate for the Energy R&D was with the National Research Council. In 1985 the Department of Energy, Mines and Resources (EMR) was given the mandate to manage the Energy R and D program for the renewable energies. This program is managed by the Efficiency and Alternative Energy Technology Branch (EAETB) of the Canadian Mineral and Energy Technology Sector called CANMET.

The Canadian Wind Energy R&D Program is part of the New Energy Supply Technology group (NEST) which in turn is a part of the Alternative Energy Division of the EAETB. The organisational chart that shows the position of the Wind Energy Program in the Department of Energy Mines & Resources is shown in Appendix A.

The wind energy R&D program is managed by the Wind Energy Technology Section of NEST, in consultation with a Technical Advisory Committee. This advisory committee consists of 6 to 8 members that represent the industry, utilities and researchers.

GOALS OF WIND ENERGY R&D

The goals of the program are to:
- improve and enlarge the technology base through r&d,
- support the industry to develop low cost, efficient and structurally sound machines and
- prove the viability of wind energy systems.

THE R&D BUDGET

The annual budgets for the wind energy R&D program, for the period of 1978 to 1991, as funded by the Panel of the Energy R&D are shown in Figure 1. The budget for the fiscal year 1991/92 is about $700,000.

The budget is used as catalytic. Most of the projects are co-funded by the contractor or some other institution/organisation. In this way the total wind energy r&d effort in canada is increased to about $1.5 To 2.0 Million dollars. Only a few basic R&D projects are fully funded from the EMR's budget.

THE R&D PROGRAM

The wind energy program can be divided into 5 areas:

WIND ENERGY CONVERSION SYSTEMS (WECS)
- basic research
- grid connected

WIND /DIESEL SYSTEMS

TEST SITES

RESOURCE ASSESSMENT

MISC.
- Canadian standards
- international activities
- conferences & workshops

The current R&D activities in the above mentioned areas are described below:

WECS R&D

Basic Research

Prof. A. Laneville, Sherbrooke Univ., Quebec
- wind tunnel tests of a NACA 0018 aerofoil
- dynamic stall
- effects of roughness

Prof. I. Paraschivoiu, Ecole Polytechnique, Montreal
- simulation par elements finis de lecoulement d'un rotor d'eolienne a axe vertical

GRID CONNECTED WECS

ADECON
- aerodynamic braking
- multiple-generator belt and pulley drive train
- construction of the 300 kW VAWT

LAVALIN-TECH
- drive train for the 24 m VAWTS
- detailed design of the high energy 24 m rotor
- fiber glass blade design for VAWTS

HYDRO QUEBEC
- evaluation of the cracked blade Bonus turbine at Kuujjuack, Quebec

WIND DIESEL SYSTEMS

ATLANTIC WIND TEST SITE (AWTS)
- upgrading wind/diesel test-bed

HYDRO QUEBEC
- high -penetration no-storage wind/diesel community system

NORWESTER
- advanced wind/diesel for remote canada

TEST SITES

AWTS
- testing wind turbines, wind/diesel systems and other wind energy related projects.

ALBERTA RENEWABLE ENERGY TEST SITE (ARETS)
- testing wind and pv water pumping systems

RESOURCE ASSESSMENT

DR. SALMON
- wind energy resource assessment S. Alberta

AWTS
- resource assessment for wind farm in PEI

MISCELLANEOUS

CANADIAN STANDARDS

- all of the CSA standards for wecs are in place except for the siting standard which is being prepared.

INTERNATIONAL ACTIVITIES

- Canada is a member of the INTERNATIONAL ENERGY AGENCY (IEA) and has been participating in the wind energy agreementssince 1977.
- Canada has also been participating in preparation of international standards for WECS through Standards Council of Canada & International Electrotechnical Commission (IEC). It is anticipated that these standards would be completed in about a year from now.

CONFERENCE & WORKSHOP SPONSORSHIPS

Every year EMR funds a wind energy seminar and co-funds the CANWEA/AWEA annual wind/diesel workshops and the annual canwea conferences.

FIELD TRIALS PROJECTS:

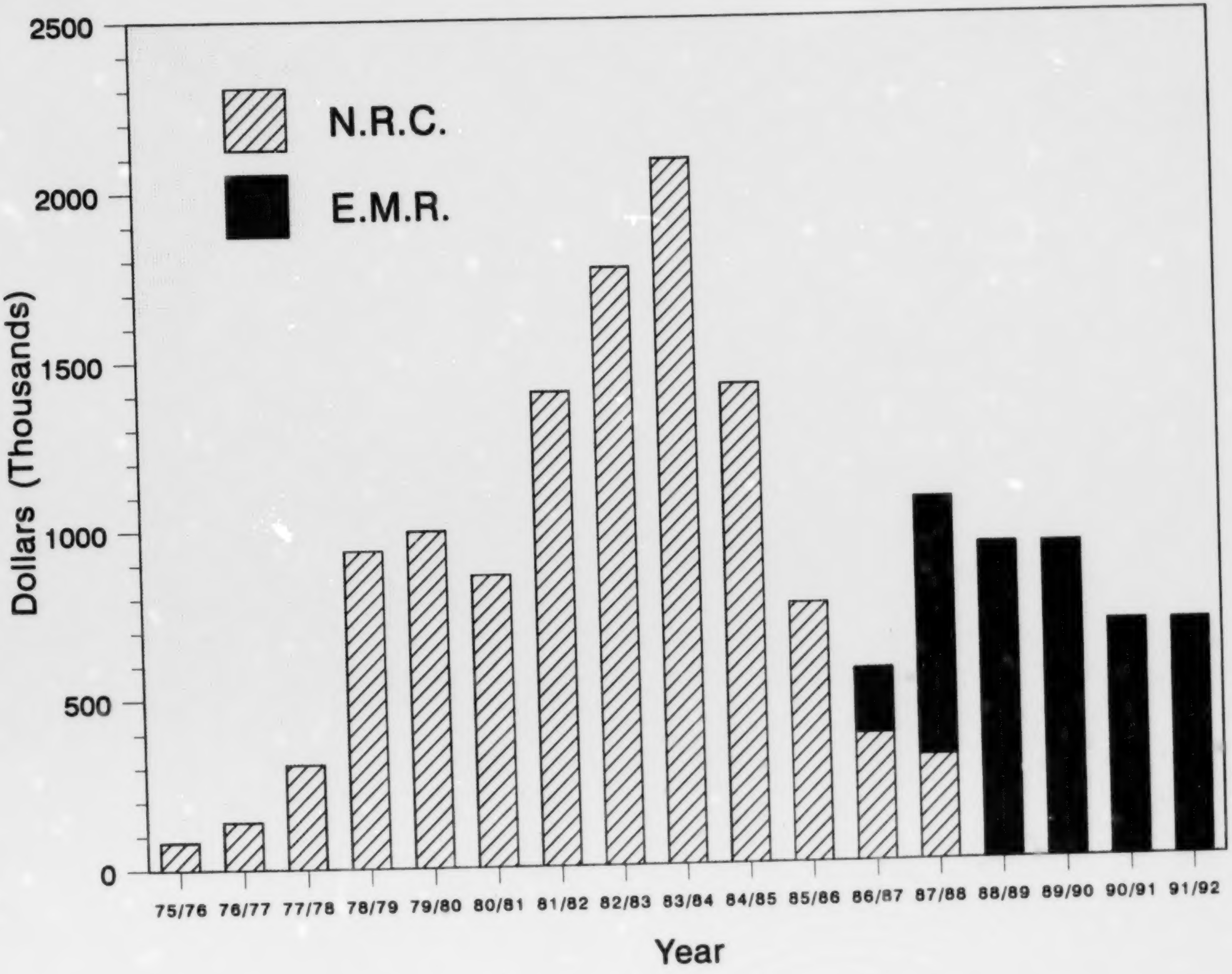
(1) 50 kw VAWT - Christopher Pt. B.C.
Manufactured by : Indal
Installed in : March 1981
Owned by : Department of National Defence
Generating time : 25,200 hours(sept. 22,1991)
Energy produced : 423.5 Mwh

(2) Eole, 4 MW VAWT, Cap Chat, Quebec
Manufactured by : Lavalin-Shawinigan
Commissioned in: March, 1988
Owned by : Lavalin- tech
generating hours: 13,000
energy produced : 8,600 MWh

(3) 3 Carter model 25 HAWTS, Cambridge Bay, NWT.
Manufactured by : Carter
Installed in : Sept. 1987
Owned by : NWT Power Corp.
Energy produced :
August : 10,800 kWh
September : 11,700 kWh
October : 16,000 kWh

(3) Aquilo, 500 kW VAWT, Atlantic Wind Test Site, PEI
Manufactured by : Indal
Installed in :
owned by : National Research Council
generating hrs. : 9723
Energy produced : 108 mwh

(5) 65 kW HAWT, Kuujjuaq, Quebec
Manufactured by : Bonus
Installed in : September ,1986
Owned by : NWT Power Corp.
Generating hrs. : 16,500
Energy produced : 310 MWh



Federal Government Wind Energy R/D Funding

APPENDIX A

ENERGY MINES & RESOURCES (EMR)

MINISTER: HON. JAKE EPP
D. MINISTER: BRUCE HOWE

8 SECTORS

MINERAL & ENERGY TECH. SECTOR (METS)

ADM M. D. EVERELL

CANMET- 4 BRANCHES

OFFICE OF ENERGY R&D (OERD)

EFFICIENCY & ALTERNATIVE ENERGY TECH. BRANCH (EAETB)

DR. D. STRANGE D. G.

3 DIVISIONS:

ALTERNATIVE ENERGY TECH. DIVISION (AED)

DR. ALLAN DOLENKO, DIRECTOR

3 GROUPS

NEW ENERGY SUPPLY TECH. (NEST)

DR. CLAUDE BARRAUD, CHIEF

WIND ENERGY + ACTIVE SOLAR + LOW HEAD HYDRO

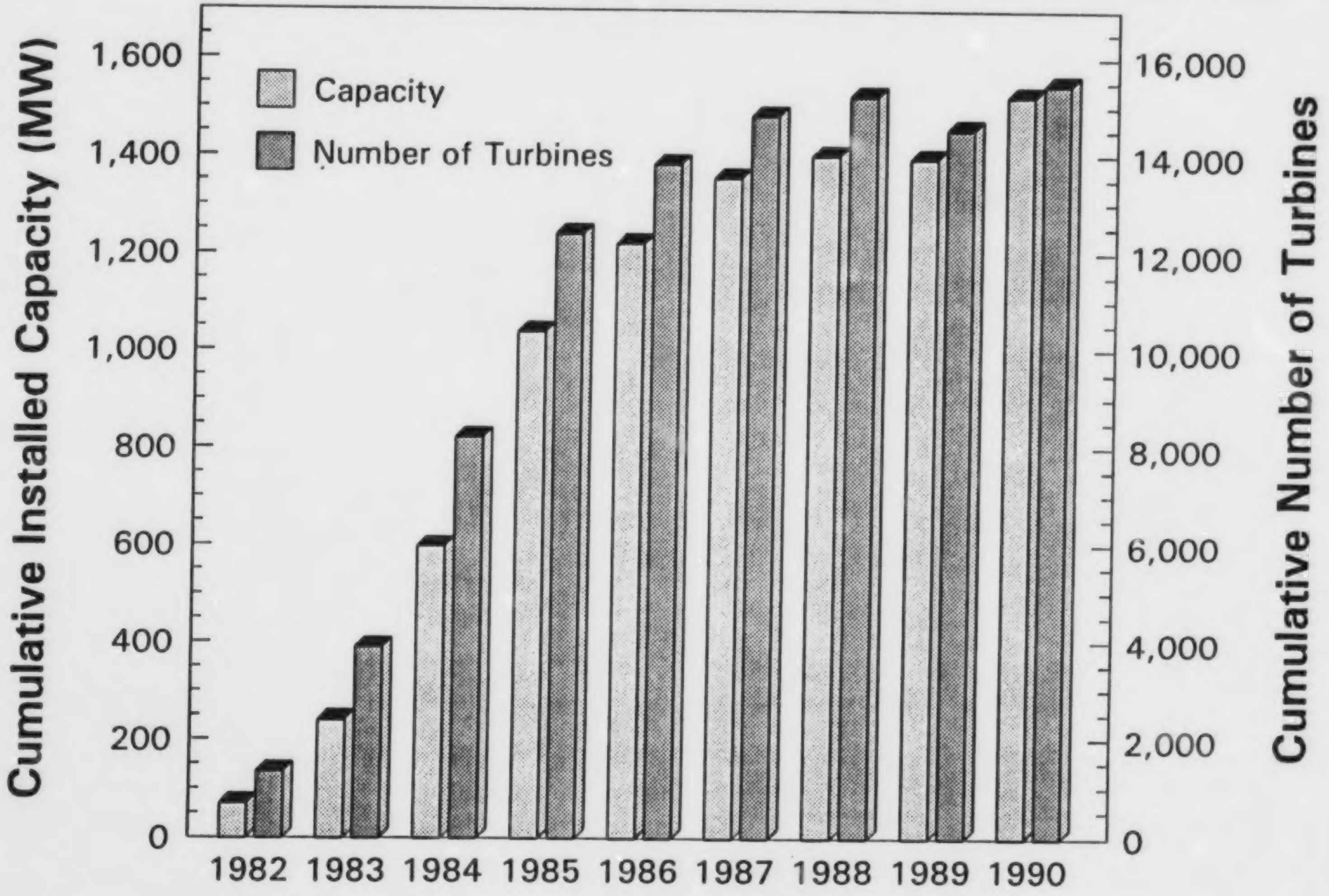
THE UNITED STATES WIND ENERGY PROGRAM

Oree Dyes
U.S. Department of Energy

GOAL OF U.S. WIND PROGRAM

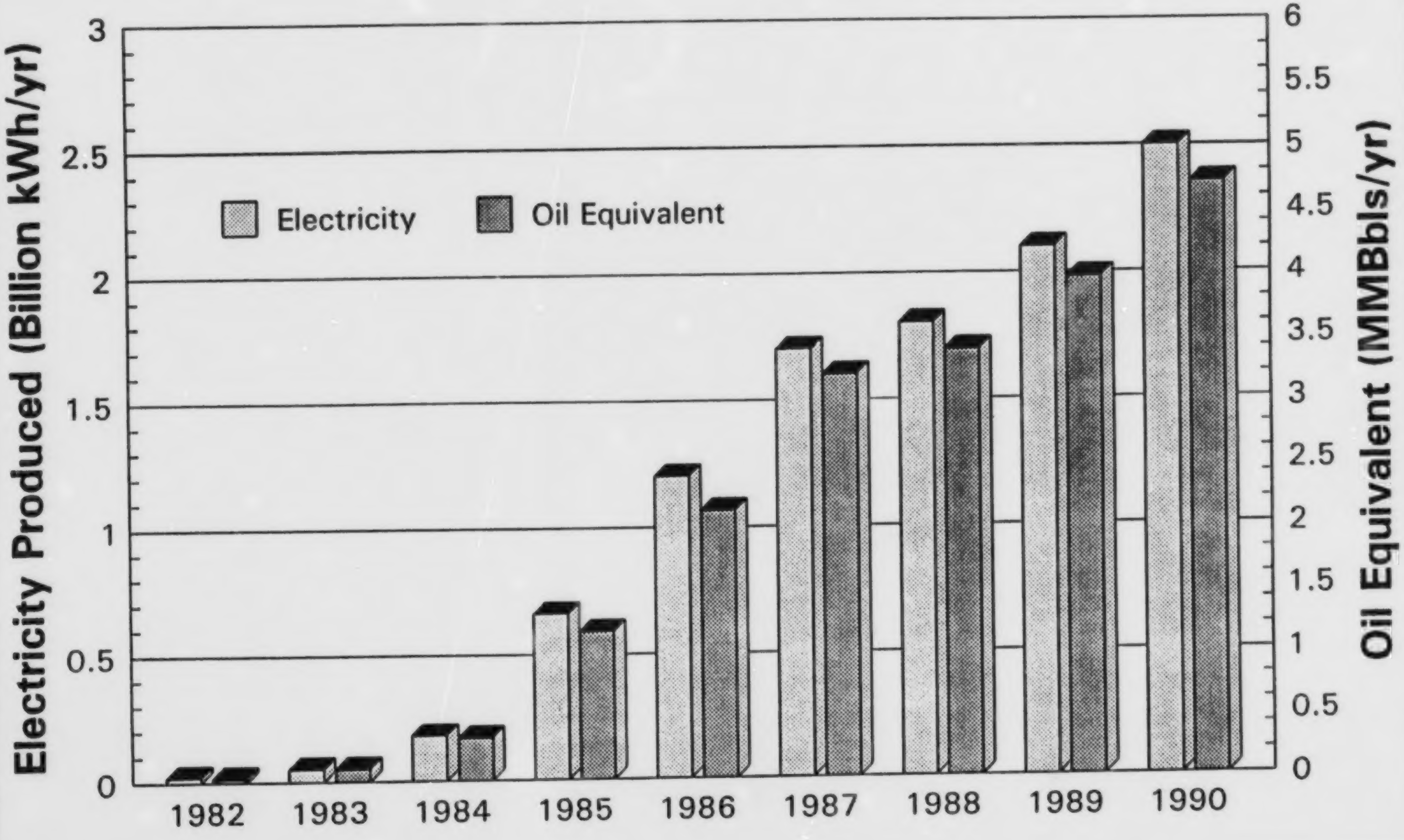
- ASSIST UTILITIES AND INDUSTRY IN DEVELOPING NEW MARKETS
- DEVELOP ADVANCED WIND TURBINE TECHNOLOGY

WIND INSTALLATIONS IN THE U.S.

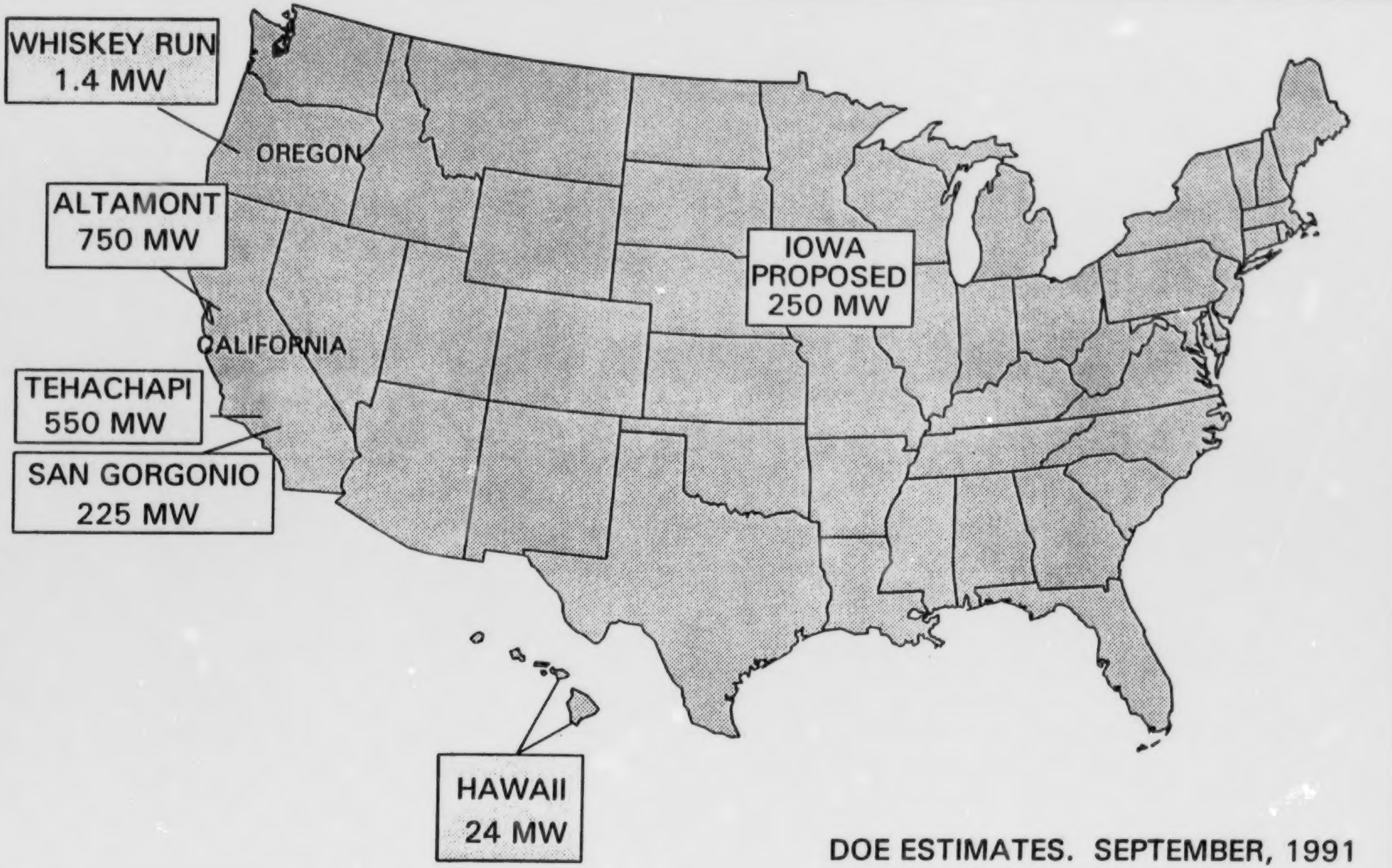


Note: Numbers include replaced/retired turbines. 1989 reflects the net installation due to approximately 200 MW (1700 turbines) retired.

WIND ENERGY PRODUCED IN THE U.S.

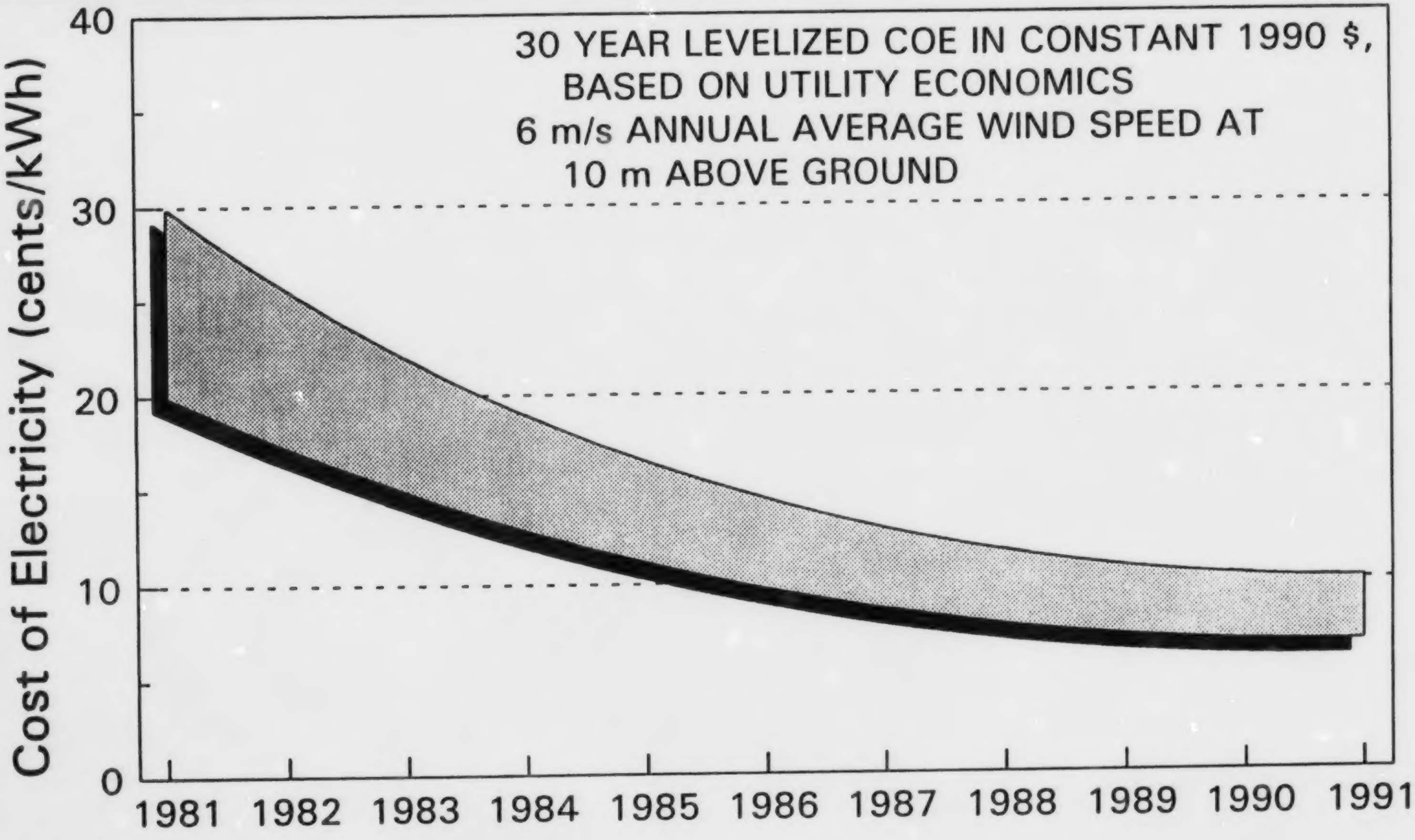


U.S. WIND POWER INSTALLATIONS

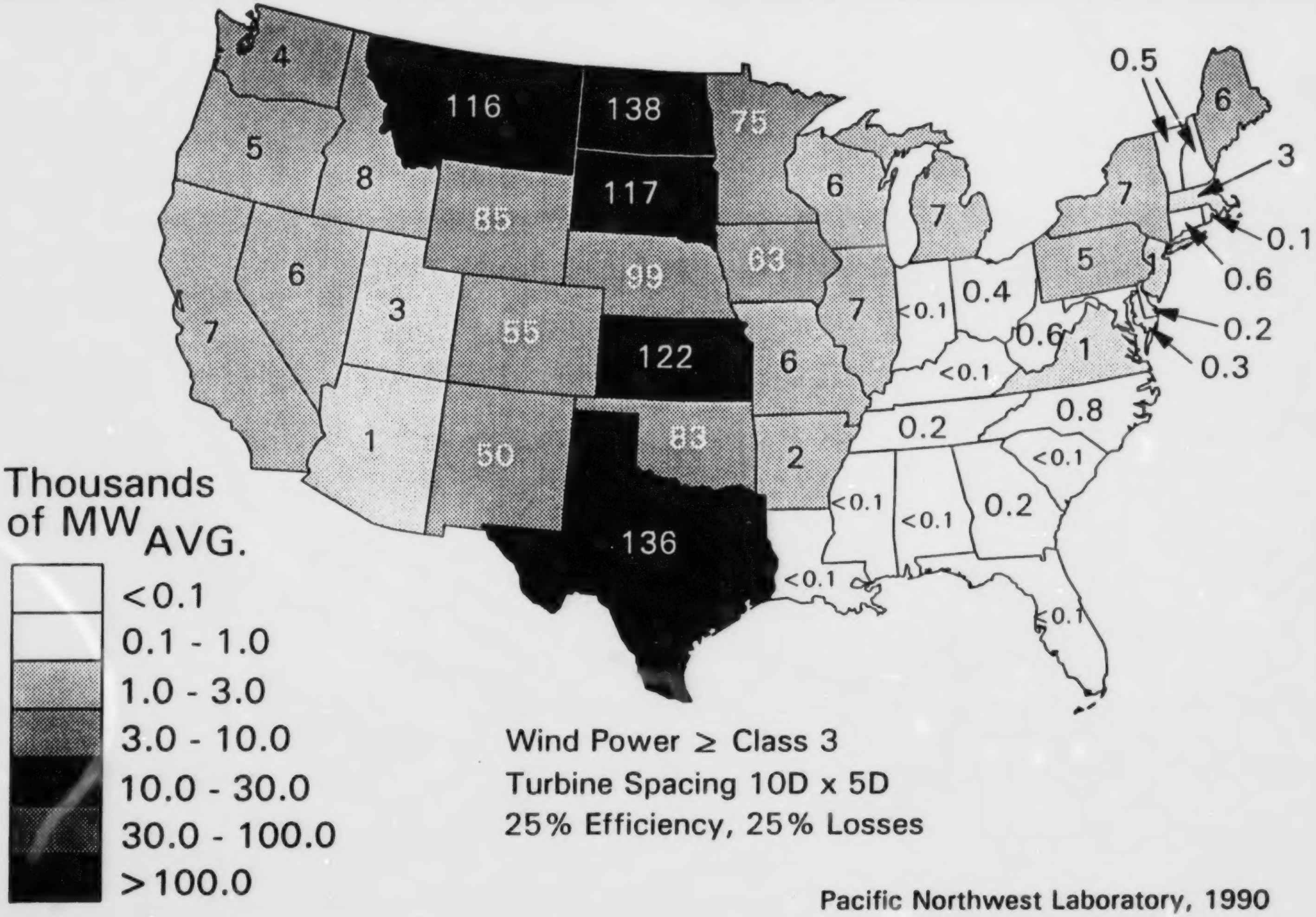

WHISKEY RUN
1.4 MW
OREGON
ALTAMONT
750 MW
CALIFORNIA
TEHACHAPI
550 MW
SAN GORGONIO
225 MW
IOWA
PROPOSED
250 MW
HAWAII
24 MW

DOE ESTIMATES. SEPTEMBER, 1991

THE COST OF ELECTRICITY HAS DECLINED



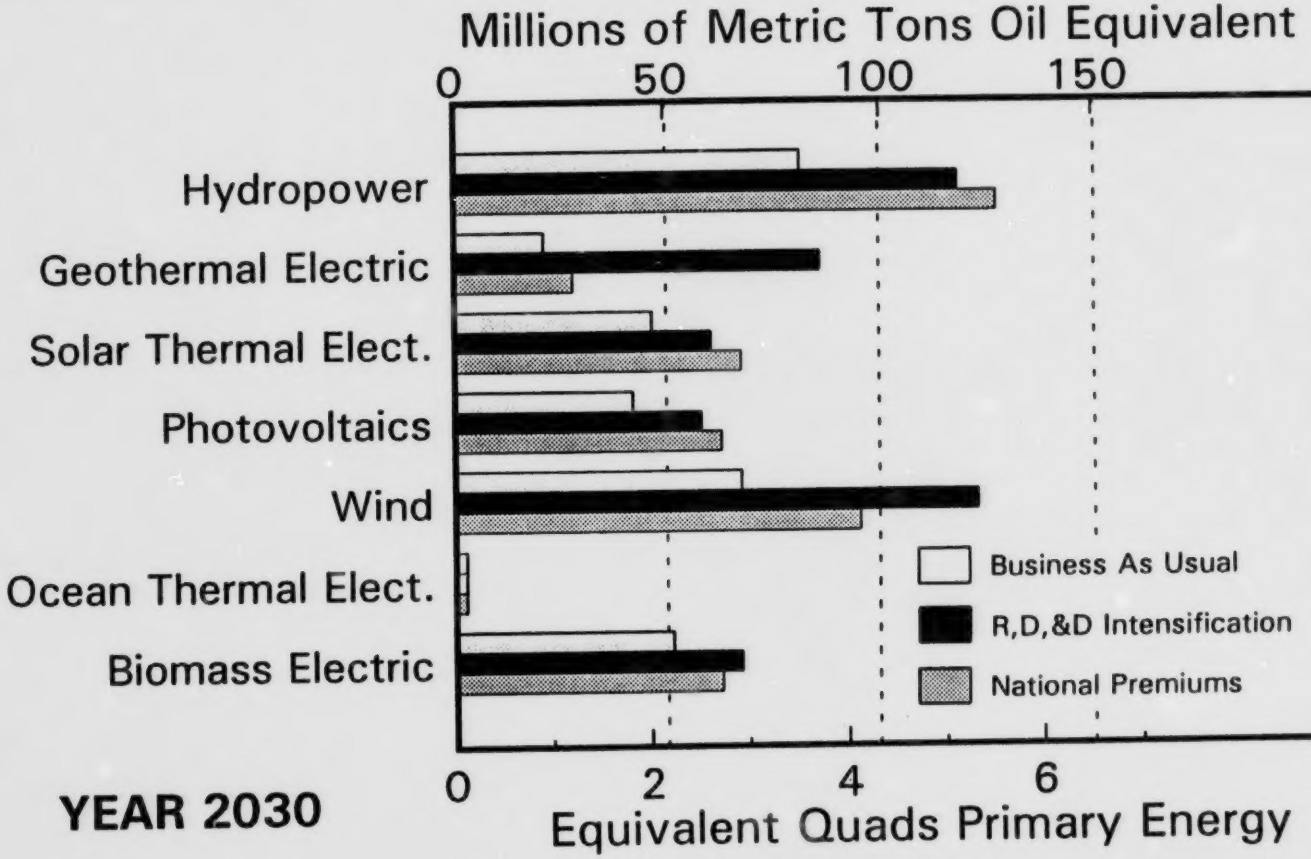
THE U.S. WIND RESOURCE IS LARGE


Thousands
of MW AVG.
<0.1
0.1 - 1.0
1.0 - 3.0
3.0 - 10.0
10.0 - 30.0
30.0 - 100.0
>100.0
4
5
7
8
6
3
1
116
85
55
50
138
117
99
122
83
136
75
63
6
2
6
7
7
<0.1
<0.1
0.4
0.6
0.2
<0.1
<0.1
0.2
0.8
<0.1
<0.1
<0.1
1
5
7
6
0.5
3
0.1
0.6
0.2
0.3

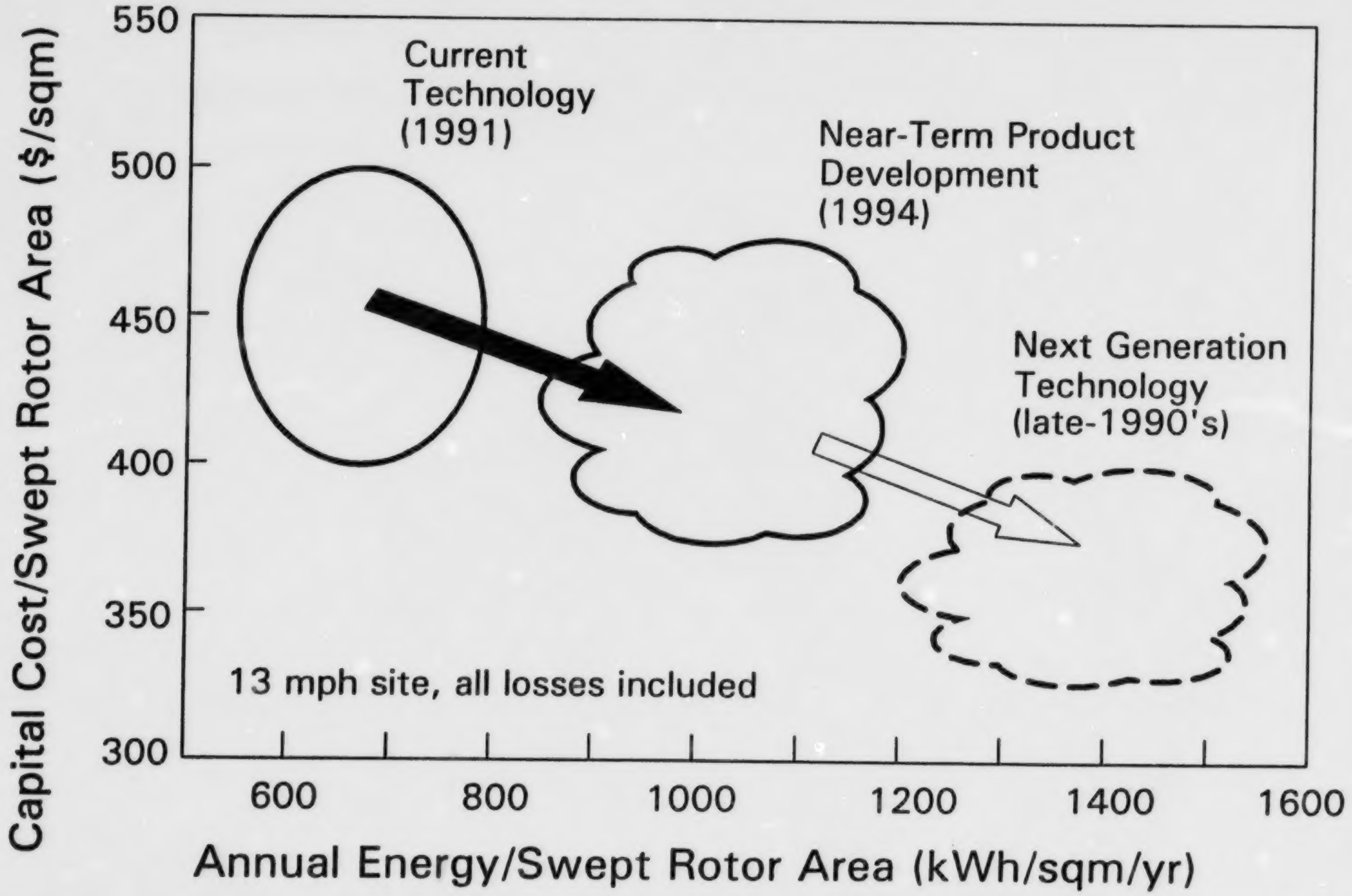
Wind Power ≥ Class 3
Turbine Spacing 10D x 5D
25% Efficiency, 25% Losses

Pacific Northwest Laboratory, 1990

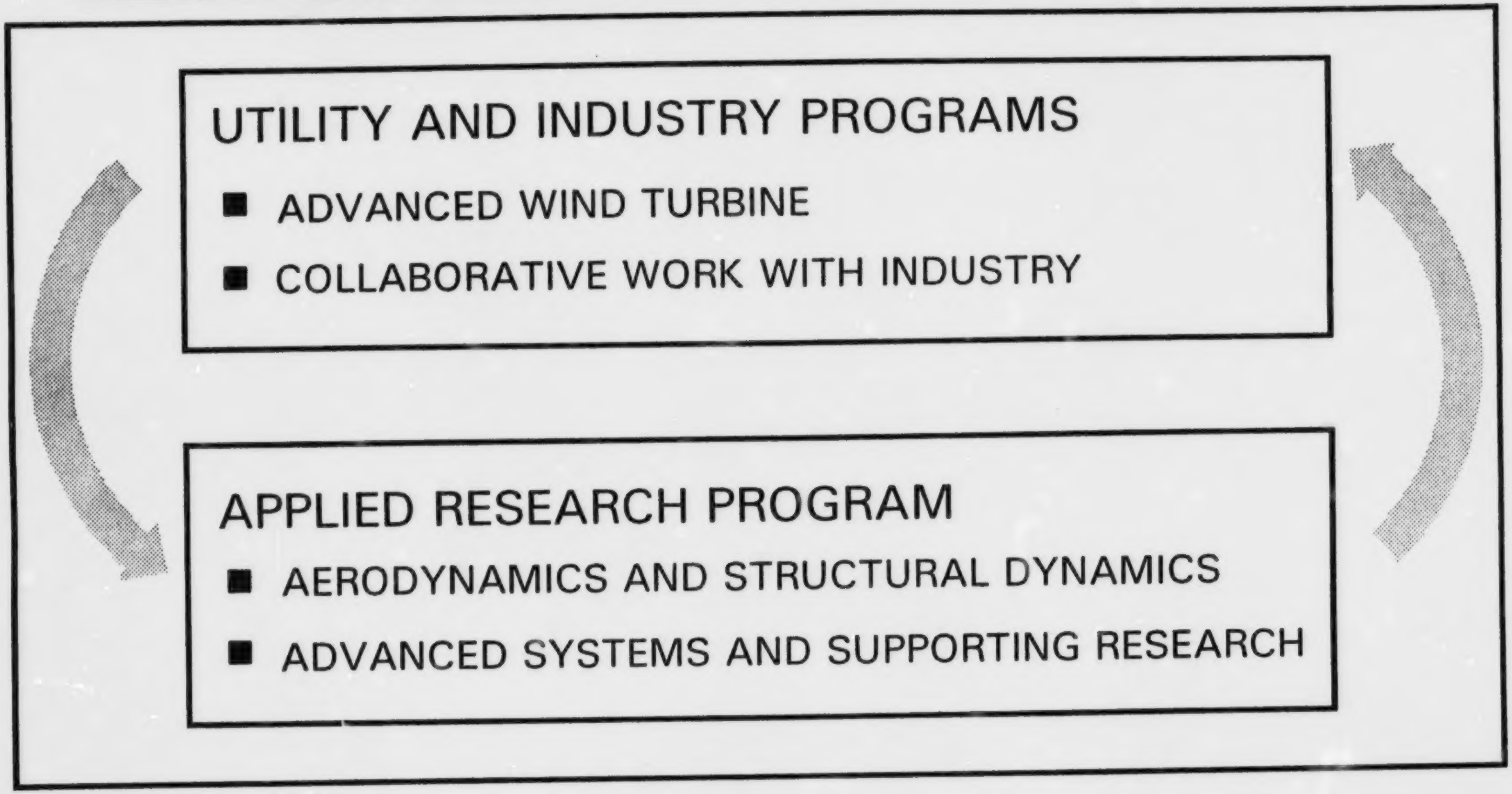
PROJECTED WIND MARKETS ARE LARGE



THE PROGRAM USES TWO TECHNICAL GOALS



TWO PROGRAM THRUSTS ARE PLANNED



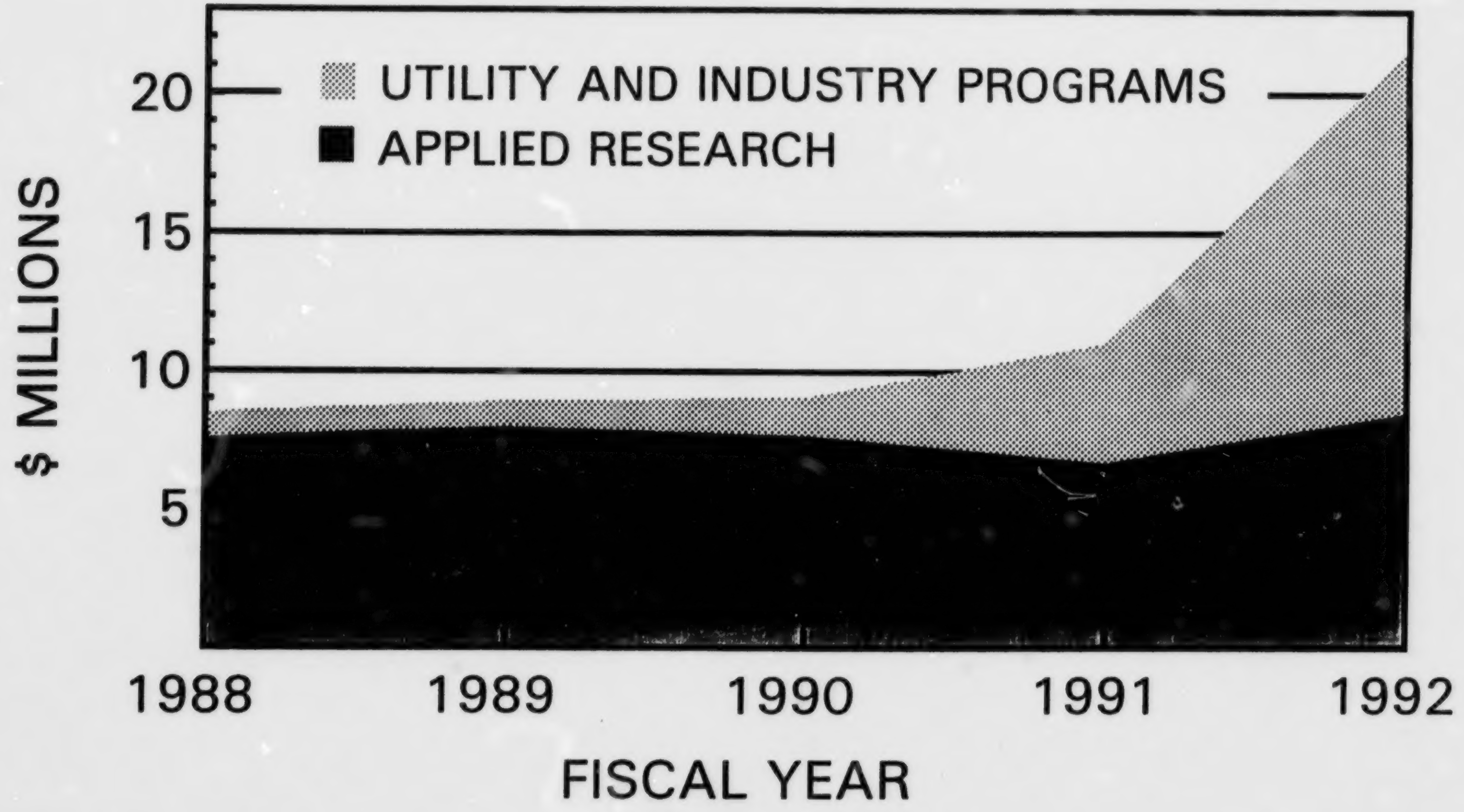
UTILITY AND INDUSTRY PROGRAMS

- ADVANCED WIND TURBINE
- COLLABORATIVE WORK WITH INDUSTRY

APPLIED RESEARCH PROGRAM

- AERODYNAMICS AND STRUCTURAL DYNAMICS
- ADVANCED SYSTEMS AND SUPPORTING RESEARCH

FEDERAL R&D BUDGET



APPLIED RESEARCH PROGRAMS

- EXTEND STRUCTURAL AND FATIGUE DATA BASES
- EXPAND FIELD TESTS TO MEASURE WIND INFLOW
- CONDUCT UNSTEADY AERO FLOW TESTS
- TEST ADVANCED COMPONENTS AND SUBSYSTEMS

UTILITY AND INDUSTRY PROGRAMS

- ■ ADVANCED WIND TURBINE PROGRAM
  - ● 1994 - NEAR-TERM PRODUCT DEVELOPMENT
  - ● LATE 1990'S - NEXT GENERATION PRODUCT DEVELOPMENT
- ■ INDUSTRY PROGRAM TO SEEK NEW COMMERCIAL OPPORTUNITIES
- ■ SUPPORT OF UTILITY WIND INDUSTRY GROUP

SUMMARY PERSPECTIVE

- LARGE WIND RESOURCE EXISTS
- SIZEABLE MARKETS PROJECTED
- TECHNOLOGY CONTINUES TO MATURE
- INCREASING UTILITY INTEREST
- ADVANCED WIND TURBINE DEVELOPMENT STARTED

Efficiency and Alternative Energy Technology Branch

CANMET

CANADIAN PARTICIPATION IN THE INTERNATIONAL ENERGY AGENCY

BY

RAJ RANGI
ALTERNATIVE ENERGY DIVISION
CANMET, ENERGY MINES &RESOURCES
OTTAWA

INTERNATIONAL ENERGY AGENCY (IEA)

THE IEA WAS ESTABLISHED BY OECD COUNTRIES IN NOVEMBER 1974 WITH ITS HEADQUARTERS IN PARIS, FRANCE

MANDATE:

TO CARRY OUT COMPREHENSIVE PROGRAM OF ENERGY COOPERATION AMONG OECD COUNTRIES

BASIC AIMS:

1. INFORMATION EXCHANGE ON INTERNATIONAL OIL MARKET

2. DEVELOP STABLE INTERNATIONAL ENERGY TRADE AND RATIONAL MANAGEMENT OF ENERGY RESOURCES

3. SHARE AVAILABLE OIL IN CASE OF EMERGENCY

4. REDUCE DEPENDENCE ON OIL THROUGH CONSERVATION AND R&D IN

ALTERNATE ENERGY SOURCES

IEA WIND ENERGY AGREEMENTS

CANADA SIGNED TWO IEA AGREEMENTS:

1. PROGRAM OF R&D ON WIND ENERGY CONVERSION SYSTEMS (WECS) SIGNED IN 1977 AND MANAGED BY AN EXECUTIVE COMMITTEE " IEA R&D WECS EC"

2. PROGRAM OF CO-OPERATION IN DEVELOPMENT OF LARGE-SCALE WECS. SIGNED IN 1985 AND MANAGED BY "IEA L.S. WECS EC"
   - AS OF DECEMBER 31,1990 THESE TWO AGREEMENTS HAVE BEEN MERGED INTO A NEW AGREEMENT - IEA R&D WIND.

IEA L.S. WECS

A FORUM FOR INFORMATION EXCHANGE ON MW SCALE WIND TURBINES / WIND FARMS

PARTICIPATING COUNTRIES GAVE REPORTS ABOUT THE SUCCESSES AND DIFFICULTIES OF THEIR PROJECTS.

THIS AGREEMENT WAS TERMINATED AS OF DECEMBER 31, 1991 AND THIS ACTIVITY HAS BECOME TASK XIII OF THE IEA R&D WIND AGREEMENT

IEA R&D WIND

CONSISTS OF CO-OPERATIVE R&D :

1. INFORMATION EXCHANGE ON NATIONAL R&D PROGRAMS

2. PARTICIPATION IN R&D PROJECTS CALLED "TASKS"

3. ANNUAL REPORT

4. TWO NEWSLETTERS PER YEAR (STARTING 1991)

EDITED BY - JACK TEMPLIN

R&D TASKS

FOLLOWING TWELVE TASKS HAVE BEEN UNDERTAKEN:

TASK I

ENVIRONMENTAL AND METEOROLOGICAL ASPECTS OF WIND ENERGY CONVERSION SYSTEMS - COMPLETED IN 1981

TASK II

EVALUATION OF MODELS OF WIND ENERGY SITING - COMPLETED IN 1983

TASK III

INTEGRATION OF WIND POWER INTO NATIONAL ELECTRICITY SUPPLY SYSTEMS - COMPLETED IN 1980

TASK IV

INVESTIGATION OF ROTOR STRESSING AND SMOOTHNESS OF OPERATION OF LARGE-SCALE WIND ENERGY CONVERSION SYSTEMS - COMPLETED IN 1980

TASK V

STUDY OF WAKE EFFECTS BEHIND SINGLE TURBINES AND IN WIND TURBINE PARKS - COMPLETED IN 1984

TASK VI

STUDY OF LOCAL WIND FLOW AT POTENTIAL WECS HILL SITES
COMPLETED IN 1985

TASK VII

STUDY OF OFFSHORE WECS - COMPLETED IN 1988

TASK VIII

STUDY OF DECENTRALIZED APPLICATIONS FOR WIND ENERGY

TECHNICALLY COMPLETED IN 1989

TASK IX

INTENSIFIED STUDY OF WIND TURBINE WAKE EFFECTS

TECHNICALLY COMPLETED IN 1990

TASK XI

BASE TECHNOLOGY INFORMATION EXCHANGE

TO BE COMPLETED IN 1991

TASK XII

UNIVERSAL WIND TURBINES FOR EXPERIMENTS (UNIWEX)

TO BE COMPLETED IN 1991

TASK XIII

COOPERATION IN THE DEVELOPMENT OF LARGE WIND TURBINE SYSTEMS

TO BE COMPLETED IN 1993

TABLE 1 --CURRENT TASKS- PARTICIPATING COUNTRIES

COUNTRY	TASKS				
	VIII	IX	XI	XII	XIII
BELGIUM*		X			
CANADA	X		X		X
DENMARK	X	X	OA		X
GERMANY			X	OA	X
ITALY		X	X		X
JAPAN					
NETHERLANDS	X	X		X	X
NEW ZEALAND	X				
NORWAY	X		X		X
SPAIN	X	X	X		X
SWEDEN	X	X	X	X	X
SWITZERLAND*	X				
UNITED KINGDOM	OA	OA	X		X
UNITED STATES	X	X			OA

* THESE COUNTRIES HAVE WITHDRAWN FROM THE AGREEMENT

OA - INDICATES COUNTRY OF OPERATING AGENT

BUDGET

CANADA'S ANNUAL (APPROX.) CONTRIBUTION FOR THE SECRETARIAT SERVICES ARE :

IEA R&D WIND = US $ 4,000

TASK XIII (LS WECS) = US $ 4,000

TASKS VIII, IX AND XI:

TOTAL EFFORT 10 PY PER TASK SHARED BY PARTICIPANTS.

TASKS XII AND XIII:

MIXED TASKS -- COST AND TASK-SHARED

TASK XI:

THIS TASK CONSISTS OF TWO SUB-TASKS:

SUB-TASK A	RECOMMENDED PRACTICES FOR WIND TURBINE TESTING AND EVALUATION
SUB-TASK B -	JOINT ACTIONS

SUB-TASK A

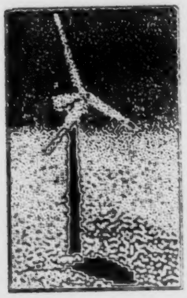
DOCUMENTS IN THE SERIES OF RECOMMENDED PRACTICES FOR WIND TURBINE TESTING AND EVALUATION

Vol.	Title	1st Ed	2nd Ed
1.	POWER PERFORMANCE TESTING	1982	1990
2.	ESTIMATION OF COST OF ENERGY FROM WECS	1983	
3.	FATIGUE CHARACTERISTICS	1984	1989
4.	ACOUSTICS. MEASUREMENT OF NOISE EMISSION FROM WIND TURBINES	1984	1988
5.	ELECTROMAGNETIC INTERFERENCE	1986	
6.	STRUCTURAL SAFETY	1988	
7.	QUALITY OF POWER. SINGLE GRID-CONNECTED WECS	1984	
8.	GLOSSARY OF TERMS	1987	

SUBTASK B

JOINT ACTIONS:

CONSIST OF SYMPOSIA AND MEETINGS OF EXPERTS IN AERODYNAMICS, FATIGUE, NOISE , GENERATING MECHANISMS ETC.
IN ALL 20 MEETINGS HAVE BEEN HELD



ECONOMICS

Vilf Moll

ONTARIO HYDRO

Non-Utility Generation

Non-Utility Generation Division Goal

To promote and establish maximum economic non-utility generation for the benefit of Ontario.

Purchase Rate For Projects Up To 5 MW

- Three components of project specific avoid costs are considered:

  1. Basic avoided cost.

  2. Adder component of up to 10 percent for projects based on:
     a) Renewable energy resources
     b) Waste-product fuels
     c) Waste-heat
     d) High efficiency energy conversion

  3. Risk off-loading adder

- Pre-approved rates - standard rate escalated annually
- Standard rate levelized over 10 years
- Differentiated time rate escalated annually
- The differentiated rate levelized over 10 years

Non-Utility Generation 1991 Standard Purchase Rates (cents/KWh)

	Winter		Summer	
	On-Peak	Off-Peak	On-Peak	Off-Peak
Basic Rate	7.36	3.00	5.97	2.66
Renewable Or High Efficiency	8.10	3.30	6.57	2.93
Renewable 10 Year Fixed Rate	9.81	3.99	7.96	3.55
At-Will	3.76	2.82	3.32	2.02

Purchase Rate for Projects Over 5 MW

- Rates determined individually for each project
- Avoided cost is governing factor

Sample Illustrative Power Purchase Rates
for a Generic 100 MW Project
In-Service Date: January, 1994

A) Illustrative Rates shown are only valid for projects with a rating between 5 MW to 150 MW (ISO) with proportionally the same power production pattern and specifications identified below. This limitation will be subject to periodic review by Hydro.

B) The illustrative rates shown are not to be considered as a rate offer but are intended only to assist the proponent with project definition. Ontario Hydro reserves the right to revise these rates at any time.

C) When the project is well defined, a formal rate offer would be provided. The formal rate offer, based on the project specific avoided cost, is subject to Hydro Senior Management approval.

	20 year contract In 1994 ¢/kWh
Energy: (All Energy)	Winter 3.0 Summer 2.5
Capacity: (On-peak Energy Only)	Winter 4.2 Summer 3.5

These rates would be applicable subject to the following conditions and assumptions:

1) The Illustrative Rates are calculated based on the following monthly average power outputs and target energy production schedule. Forced and maintenance outages are not included in the schedule.

MONTH	AVERAGE OUTPUT (MW)	TARGET ENERGY PRODUCTION	
		ON-PEAK (MWh)	OFF-PEAK (MWh)
JANUARY	100	33,800	40,600
FEBRUARY	100	32,400	35,400
MARCH	100	35,600	38,800
APRIL	90	28,800	36,000
MAY	90	31,320	35,640
JUNE	90	31,140	33,660
JULY	90	29,340	37,620
AUGUST	90	31,680	35,280
SEPTEMBER	90	28,620	36,180
OCTOBER	100	33,800	40,600
NOVEMBER	100	35,200	36,800
DECEMBER	100	31,800	42,600
TOTAL		383,500	449,180

A different set of illustrative rates would be provided on request for projects with different specifications (such as different monthly average output, project in-service date, etc.)

2) Rates shown exclude component 2 adder (up to 10%).

3) Project in-service date: January 1994.

4) Contract term: 20 years.

5) A 15 year fuel supply contract with price and terms satisfactory to Hydro shall be obtained by the proponent. The fuel supply offers and contracts must be reviewed by Hydro prior to execution by the proponent.

6) The rates would be indexed to the rate charged by Hydro to its Direct Customers for the supply of firm power at the connection voltage (115 kV or 230 kV) calculated at 100% capacity factor. Rate adjustment would be made only once each year in January. The first adjustment would occur on January 1, 1995.

7) Energy rates would apply to all energy delivered.

8) Capacity rates would only apply to energy delivered during on peak hours.

9) Capacity payment would only be made if 80% of the monthly targeted on-peak energy is delivered. Monthly targeted on peak energy would be specified by the proponent in the Power Purchase Contract.

10) Capacity rates would not apply to on-peak energy delivered in excess of the targeted amount per month unless approved by Hydro.

11) On-peak hours mean 7:00 am to 11:00 pm Monday to Friday except Statutory Holidays.

12) Winter means October to March inclusive.

13) Summer means April to September inclusive.

14) Hydro shall have the right to curtail energy delivery during 600 summer off-peak hours. No payment will be made for the curtailed energy. The level of curtailment would be negotiated and would not interfere with the project's ability to supply steam to the steam host.

Association canadienne
de l'Énergie éolienne

Tarif de rachat d'Hydro-Québec

par Jean Claude Richard

1991 - 11 - 05

Hôtel Le Grand
Montréal, Québec

Bonjour Mesdames et Messieurs,

Je suis heureux d'avoir l'occasion de vous parler des tarifs d'achat d'électricité d'Hydro-Québec pour l'électricité produite par des producteurs indépendants au Québec. Mais en premier, j'aimerais prendre quelques minutes pour vous présenter Hydro-Québec.

Hydro-Québec est responsable de fournir l'électricité aux clients dans la province de Québec. A la fin de l'année 1990, sa puissance installée était de 25 682 MW. De plus Hydro-Québec achète la presque totalité de la production de la centrale Churchill Falls, centrale ayant une puissance nominale de 5 428 MW.

Notre capacité de 25 682 MW est répartie comme suit:

- 53 centrales hydrauliques	23 927 MW
- 26 centrales thermiques	1 755 MW
pour un total de 79 centrales	25 682 MW

Des 26 centrales thermiques, 4 sont branchées sur le réseau intégré alors que les autres sont situés dans des réseaux isolés. Ces réseaux isolés sont situés aux Îles-de-la-Madeleine, sur la Basse Côte Nord, sur l'île d'Anticosti et dans le Nord de la province de Québec.

Les Centrales thermiques reliés au réseau intégré sont Gentilly 2 (nucléaire) 685 MW, Tracy (mazout #6) 600 MW, La Citière (TAG) 201 MW et Cadillac (TAG) 162 MW. Les centrales thermiques dans les réseaux isolés sont principalement des machines diesels mais Hydro-Québec vient d'inaugurer une nouvelle centrale aux Îles-de-la-Madeleine qui utilise de mazout #6 au lieu du mazout #2.

Dans le réseau intégré, Hydro-Québec utilise presqu'uniquement de la production hydraulique pour répondre à la demande.

Le plan de développement 1990-1992 Horizon 1999, publié au début de l'année 1990, montre que dans le scénario moyen de la demande, les besoins en énergie du Québec augmentent en moyenne de 2,6% entre 1989 et 2006 pour atteindre environ 200 TWh. Ces besoins sont par contre réduits par les programmes d'efficacité énergétique à un taux de croissance moyen de 2% par année; la demamde en l'an 2006 est alors de 179,3 TWh.

Nos centrales hydrauliques et nos achats de Churchill Falls peuvent nous fournir 165,5 TWh par année en moyenne.

Pour rencontrer les nouveaux besoins, Hydro-Québec peut utiliser le potentiel sur les petites et grandes rivières, pas encore développé.

Le potentiel des grandes rivières est d'envirion 200 TWh annuellement. A un facteur d'utilisation de 60%, ceci représente un potentiel de 40 000 MW. De ce potentiel, environ 18 000 MW ou 100 TWh est économiquement viable.

Plus que 400 petites rivières offrent un potentiel de 10 000 MW mais une large partie de celui-ci ne peut pas être développé économiquement avec les conditions existantes.

Tout celà pour vous dire qu'Hydro-Québec alimente son réseau intégré avec de la production hydraulique et que nous croyons pouvoir continuer à le faire encore pour plusieurs années. Il n'est donc pas question pour Hydro-Québec d'offrir un prix d'achat, pour l'électricité livrée sur le réseau intégré, qui est fonction du prix d'un combustible fossil.

Le prix d'achat pour de l'énergie produite par éolienne sur le réseau intégré serait de 4,22¢/kWh en 1991. Ce prix serait augmenté annuellement selon l'indice des prix à la consommation mais pas plus que 6%.

Hydro-Québec ne s'attend pas de recevoir des projets d'éolienne à ce prix et en conséquence je vais vous parler maintenant de nos réseaux isolés.

Comme je l'ai déjà mentionné, Hydro-Québec alimente plusieurs régions du Québec avec des machines diesels et en conséquence notre coût de production est de beaucoup supérieur au 4,22¢/kWh. Par contre, Hydro-Québec travaille très fort pour réduire ces coûts. Tel que mentionné plus tôt, Hydro-Québec vient d'inaugurer une nouvelle centrale au Îles-de-la-Madeleine. Les nouvelles machines utilisent du mazout #6 et peuvent produire 5,1 kWh par litre.

Nous espérons mettre en service la centrale du lac Robertson sur la basse Côte Nord. Cette centrale nous permettra d'arrêter certaines centrales thermiques durant les conditions normales d'exploitation durant plusieurs années.

Il y a encore des possibilités pour implanter des éoliennes dans les réseaux isolés mais je crois que les spécialistes doivent continuer à améliorer les automatismes pour permettre une plus grande utilisation de la production éolienne par rapport à la production diesele et aussi à réduire le coût des éoliennes.

Le tableau ci-joint vous donne un estimé du coût de production variable à différent endroits dans la province.

J'espère que je n'ai pas découragé tous les promoteurs et que j'aurai l'occasion de négocier un contrat d'achat pour un projet d'éolienne.

Merci de votre attention et j'espère que j'ai quelques minutes pour répondre à des questions.

Hydro-Québec
Coûts évités pour la production d'électricité par éolienne

	Type de combustible	Rendement centrale thermique (kWh/l)	Prix du combustible ($/l)	Coût de production variable ($/kWh)	Formule d'indexation
■ **Réseau intégré**	n.a.	n.a.	n.a.	0,0422	IPC - Max 6%
■ **Réseaux isolés**					
Îles-de-la-Madeleine					
Vieille centrale (1989)	Mazout #2 et #5	4,0	0,184	0,066	Coût du combustible
Nouvelle centrale (1992)	Mazout #6 (1,5% S)	5,1	0,179	0,055	
Basse Côte-Nord	Mazout #2	3,4	0,240	0,071	Coût du combustible
Nouveau-Québec	Mazout #2	3,0	0,511	0,170	Coût du combustible
Ungava	Mazout #2	3,2	0,443	0,138	Coût du combustible

THE CANADIAN WIND ENERGY ASSOCIATION

ANNUAL MEETING

LE GRAND HOTEL

MONTREAL, QUEBEC

NOVEMBER 4-7, 1991

LOUISE D. LANOY
SENIOR OFFICER
INVESTMENT CANADA

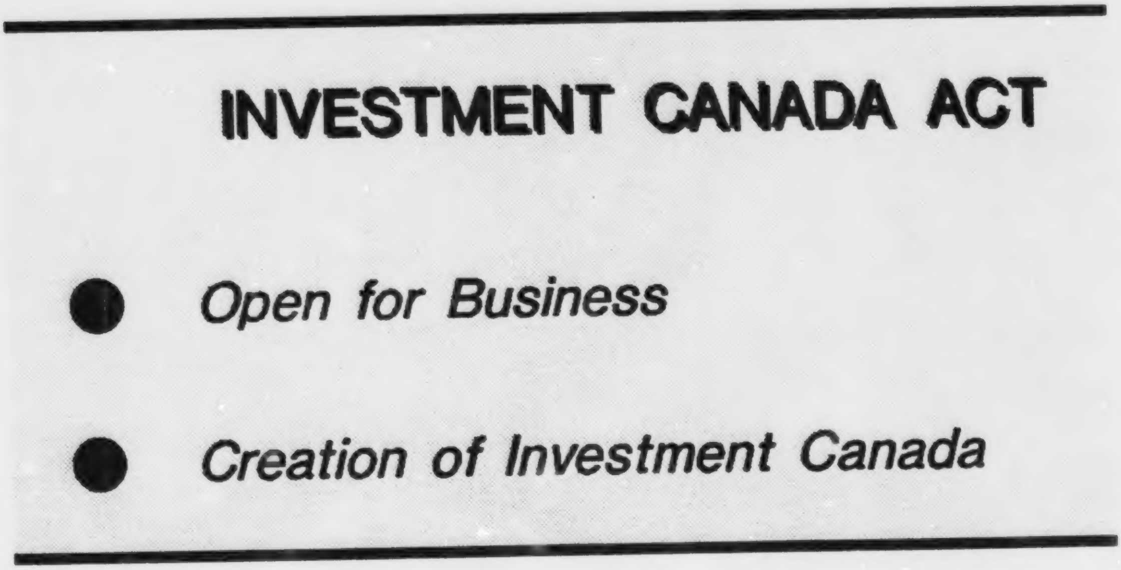
LADIES AND GENTLEMEN

I WISH TO THANK MR. RAJ RANGI, DEPARTMENT OF ENERGY, MINES AND RESOURCES FOR SUGGESTING TO YOUR PRESDIDENT, MR. REAL REID, THAT INVESTMENT CANADA BE INCLUDED ON YOUR PROGRAM.

WE ALWAYS WELCOME AN OPPORTUNITY TO SPEAK ABOUT INVESTMENT CANADA, WHO WE ARE, WHAT WE DO, HOW WE DO IT, AND WHAT WE CAN DO FOR YOU.

SLIDE 1 - INVESTMENT CANADA

SLIDE 2 - INVESTMENT CANADA ACT



INVESTMENT CANADA ACT

- *Open for Business*
- *Creation of Investment Canada*

INVESTMENT CANADA ACT OF JUNE 1985 CREATED THE INVESTMENT CANADA AGENCY. THE AGENCY REPLACED THE FOREIGN INVESTMENT REVIEW AGENCY.

THE CREATION OF THE INVESTMENT CANADA SENT A CLEAR MESSAGE TO THE WORLD THAT CANADA WAS OPEN FOR BUSINESS AND A GOOD PLACE TO INVEST.

INVESTMENT
CANADA

INVESTISSEMENT
CANADA

SLIDE 3 - FOREIGN DIRECT INVESTMENT - VALUE OF FOREIGN OWNED ASSETS

THIS SLIDE CLEARLY ILLUSTRATES THAT WE HAVE BEEN SUCCESSFUL AT GETTING THIS MESSAGE OUT TO THE INVESTING PUBLIC. THE STOCK OF FOREIGN OWNED ASSETS HAS GROWN FROM $87.2 BILLION TO $119.2 BILLION - AN INCREASE OF 27% OVER THE FIVE-YEAR PERIOD 1985-1989.

SLIDE 4 - DISTRIBUTION OF FDI STOCK IN CANADA

THIS NEXT SLIDE SHOWS THE DISTRIBUTION OF FOREIGN DIRECT INVESTMENT STOCK IN CANADA 1984 AND 1989.

THIS IS PROBABLY NO SURPRISE, BUT WE CAN SEE FROM THIS SLIDE A SIGNIFICANT GROWTH IN INVESTMENT FROM JAPAN AND THE PACIFIC RIM COUNTRIES AND RESPECTABLE GROWTH FROM THE U.K. AND GERMANY.

RAPIDLY GROWING
FOREIGN DIRECT INVESTMENT, 1979-1989
STOCK OF FOREIGN-OWNED ASSETS

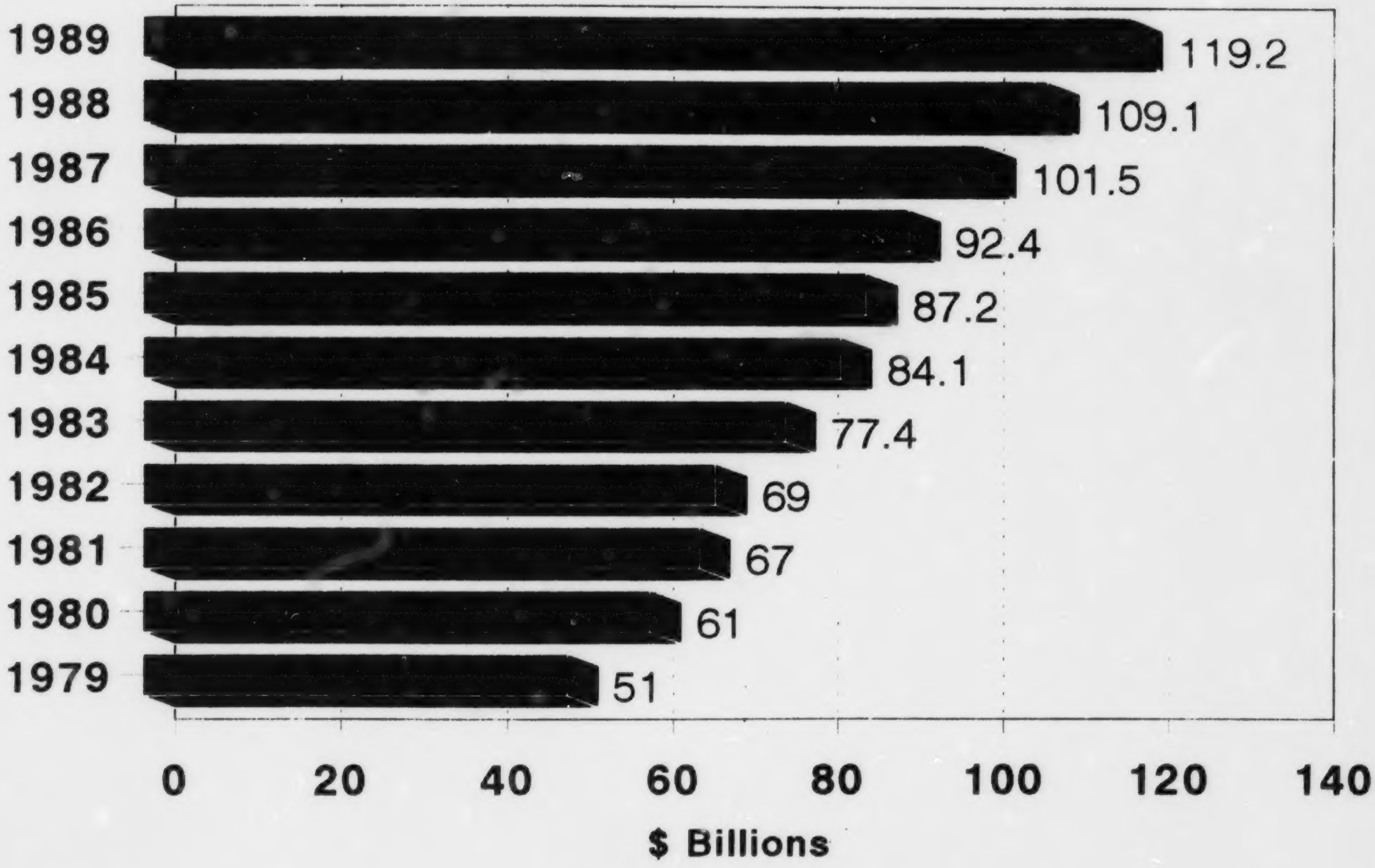
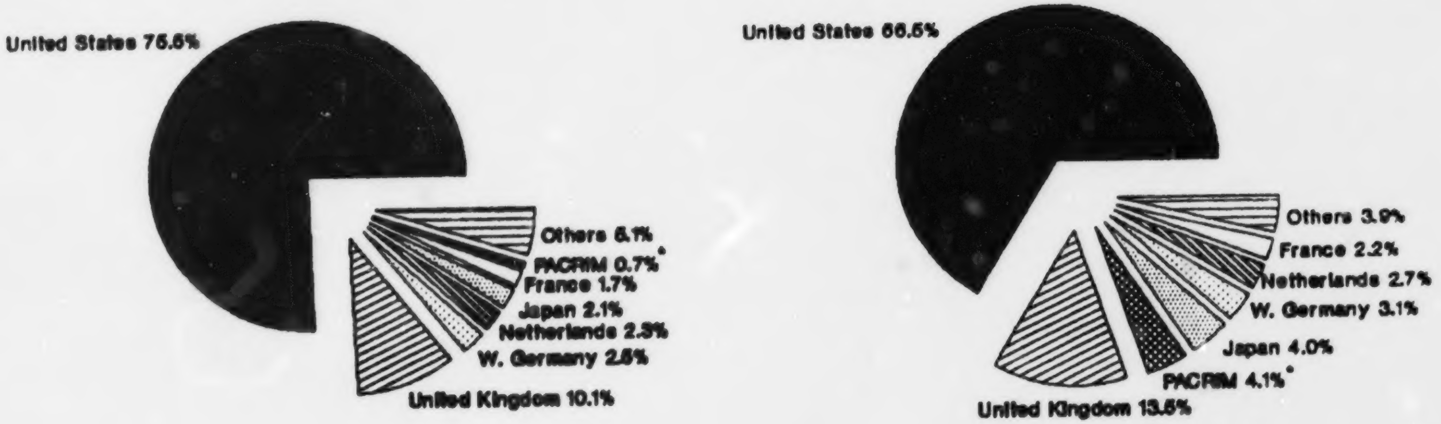


Chart 2
Distribution of FDI in Canada by Area of Ownership

1983 & 1989



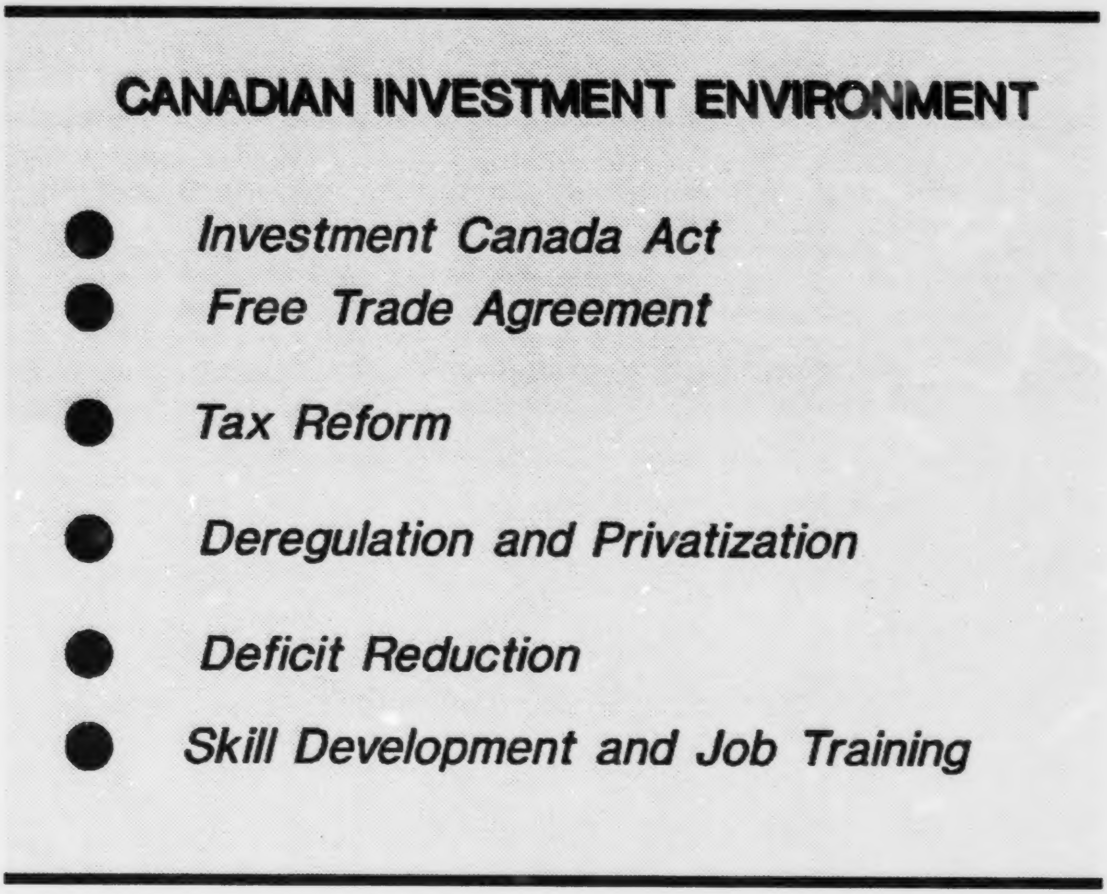
1983 Total = $ 77.4 Billion

1989 Total = $ 118.5 Billion

*** The Pacific Rim excludes Japan**

***Source*: Investment Canada compilations using data from Statistics Canada.**

SLIDE 5 - CANADIAN INVESTMENT ENVIRONMENT



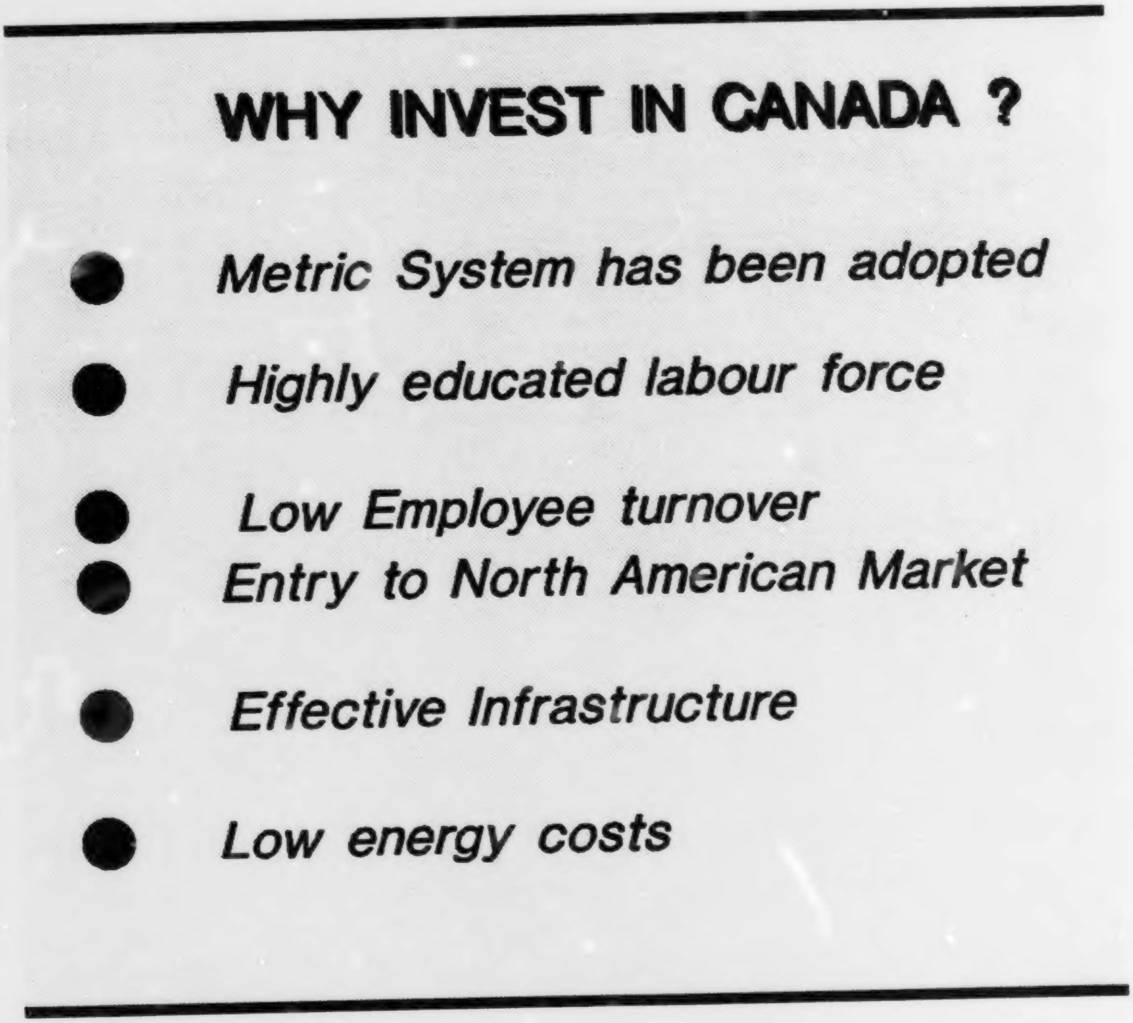
CANADIAN INVESTMENT ENVIRONMENT

- *Investment Canada Act*
- *Free Trade Agreement*
- *Tax Reform*
- *Deregulation and Privatization*
- *Deficit Reduction*
- *Skill Development and Job Training*

MANY OF THESE FOREIGN INVESTORS AGREE THAT CANADA HAS A FABOURABLE INVESTMENT CLIMATE.

TO THIS LIST WE CAN ADD

SLIDE 6 - WHY INVEST IN CANADA?

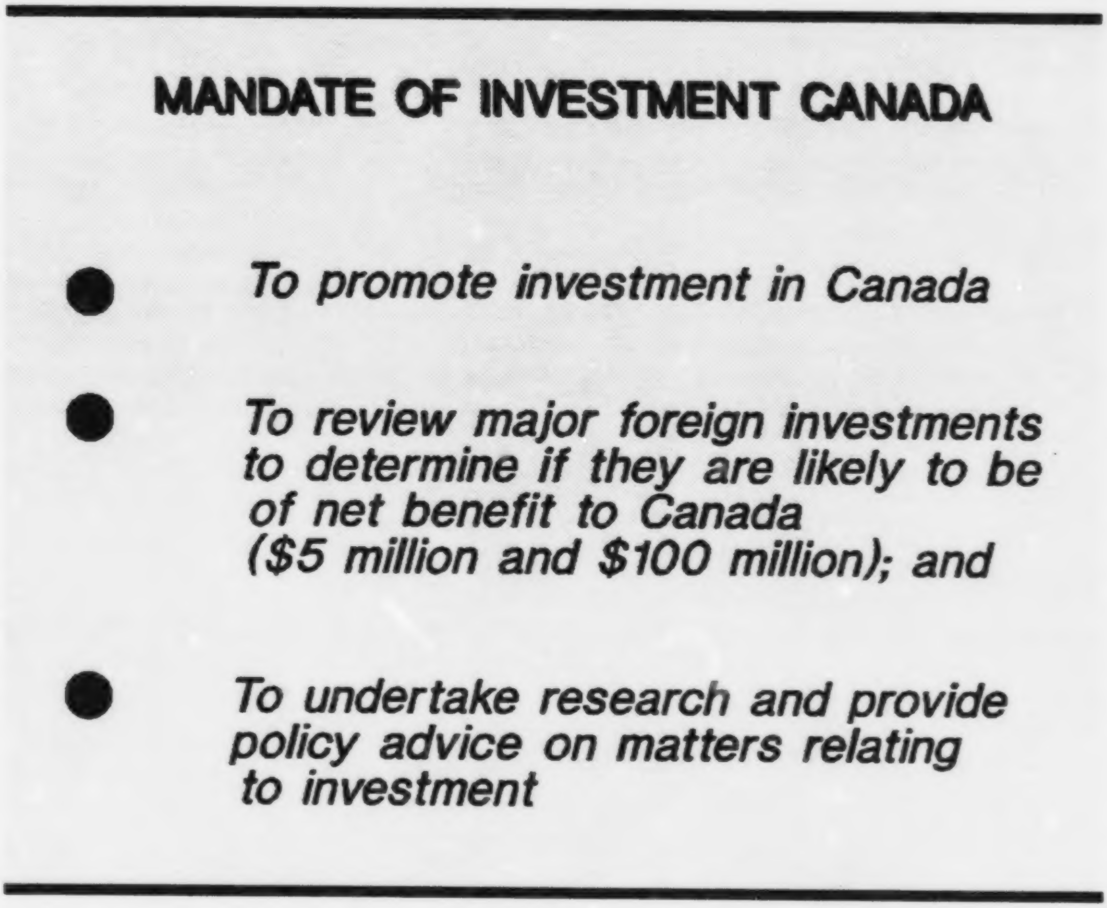


WHY INVEST IN CANADA ?

- Metric System has been adopted
- Highly educated labour force
- Low Employee turnover
- Entry to North American Market
- Effective Infrastructure
- Low energy costs

NOW, LET US TURN OUR ATTENTION TO INVESTMENT CANADA, OUR MANDATE, OUR ORGANIZATIONAL STRUCTURE AND THE SERVICES WE PROVIDE TO INVESTORS IN GENERAL AND HOW WE COULD ASSIST YOU.

SLIDE 7 - MANDATE OF INVESTMENT CANADA

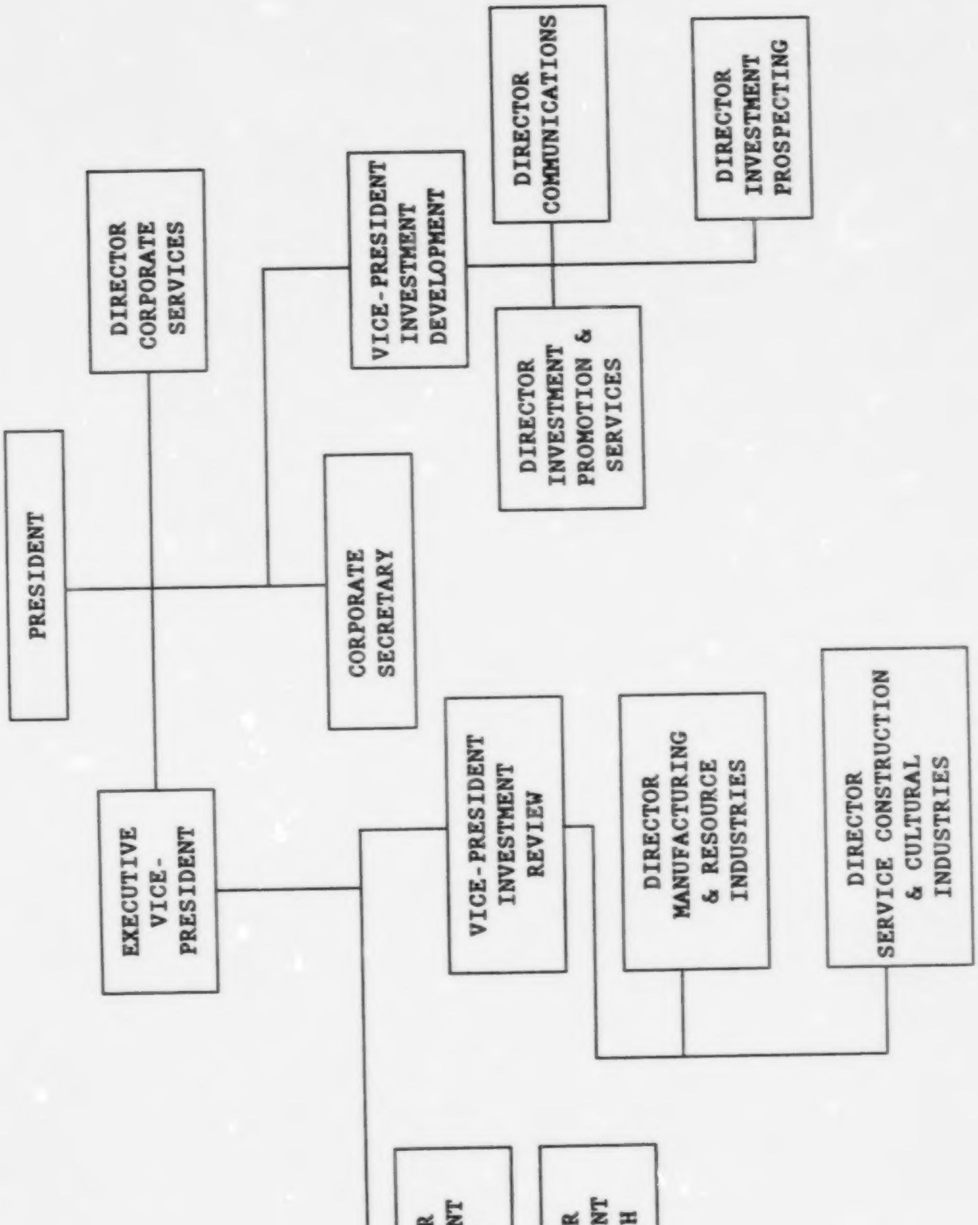


MANDATE OF INVESTMENT CANADA

- *To promote investment in Canada*
- *To review major foreign investments to determine if they are likely to be of net benefit to Canada ($5 million and $100 million); and*
- *To undertake research and provide policy advice on matters relating to investment*

SLIDE 8 - ORGANIZATION CHART

I BELONG TO THIS GROUP, THE INVESTMENT PROMOTION AND SERVICES GROUP, AND EUROPE IS MY TERRITORY.


PRESIDENT
CORPORATE SECRETARY
DIRECTOR CORPORATE SERVICES
EXECUTIVE VICE-PRESIDENT
VICE-PRESIDENT INVESTMENT DEVELOPMENT
DIRECTOR COMMUNICATIONS
DIRECTOR INVESTMENT PROSPECTING
DIRECTOR INVESTMENT PROMOTION & SERVICES
VICE-PRESIDENT INVESTMENT REVIEW
DIRECTOR MANUFACTURING & RESOURCE INDUSTRIES
DIRECTOR SERVICE CONSTRUCTION & CULTURAL INDUSTRIES
DIRECTOR INVESTMENT POLICY
DIRECTOR INVESTMENT RESEARCH

SLIDE 9 - SERVICES TO THE INVESTOR

SERVICES TO INVESTORS

- *Information on:*
  - *- Market data*
  - *- Costs of production inputs*
  - *- Investment location*
  - *- Government regulations and incentives*
  - *- Sources of financing*
  - *- Investment opportunities*
- *Matchmaking*
- *Introduction to right contacts*

ROMY PETERS AND I ARE RESPONSIBLE FOR INVESTMENT PROMOTION AND SERVICES FOR EUROPE. WE OFFER ONE-STOP SHOPPING. WE HAVE A VERY BROAD NETWORK OF CONTACTS AT THE FEDERAL, PROVINCIAL AND MUNICIPAL LEVELS FOR SOURCING POTENTIAL PARTNERS.

WE HAVE A 500 PAGE DATA BASE OF INFORMATION ON HOW TO ESTABLISH A BUSINESS IN CANADA

GATHER "SECONDARY" MARKETS INTELLIGENCE AND OTHER MATERIAL PERTINENT TO YOUR INVESTMENT IN CANADA, AND PACKAGE IT IN A "PERSONALIZED BRIEFING BOOK".

WE WILL PLAN, ORGANIZE YOUR INCOMING MISSION TO CANADA (TRAVEL AT YOUR EXPENSE) AND WILL ACCOMPANY YOU (AT OUR EXPENSE) ON THE MISSION.

IN ADDITION, WE HAVE DEVELOPED A SIMPLE FORMAT TO ASSIST THE INVESTOR SIFT THROUGH THE MOUNTAINS OF INFORMATION YOU WILL RECEIVE FROM EACH MUNICIPALITY VISITED DURING YOUR TRIP.

IF YOU HAVE SPECIAL NEEDS, FINANCING, ACCOUNTING, R & D OR OTHER PROFESSIONAL REQUIREMENTS, WE WILL ENSURE THAT YOU MEET THE APPROPRIATE PEOPLE DURING YOUR PROGRAM.

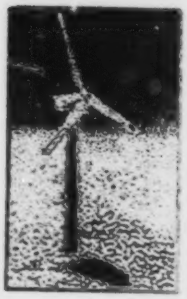
IF YOU ARE A CANADIAN COMPANY SEEKING A FOREIGN PARTNER, OR FOREIGN TECHNOLOGY OR TO EXPAND YOUR BUSINESS IN CANADA, INVESTMENT CANADA IS AT YOUR SERVICE. WE ARE A PHONE CALL AWAY FROM EVERY CANADIAN EMBASSY AND CONSULATE AROUND THE WORLD.

SLIDE 10 - LIST OF CONTACTS

OUR FAX NUMBER IS 613-996-2515.

LIST OF CONTACTS
INVESTMENT PROMOTION AND SERVICES GROUP

DIRECTOR MICHEAL KELLY	(613) 992-4916
MANAGER, EUROPE ROMY PETERS	(613) 995-7920
SENIOR OFFICER, EUROPE LOUISE D. LANOY	(613) 996-7865
MANAGER, NORTH AMERICA AUDREY TURNER	(613) 995-0759
SENIOR OFFICER GEORGE WOODS	(613) 995-7280
OFFICER SUSAN GATES	(613) 996-4292
MANAGER, ASIA HENRY YAU	(613) 995-6634
MANAGER, JAPAN RICHARD LOVATT	(613) 992-5204



WIND TURBINE DEVELOPMENT

The Federal Advanced Wind Turbine Program

Palmer Carlin, NREL

A major DOE, multi-year project

- Cost-shared with industry
- DOE projected budget of $75 million

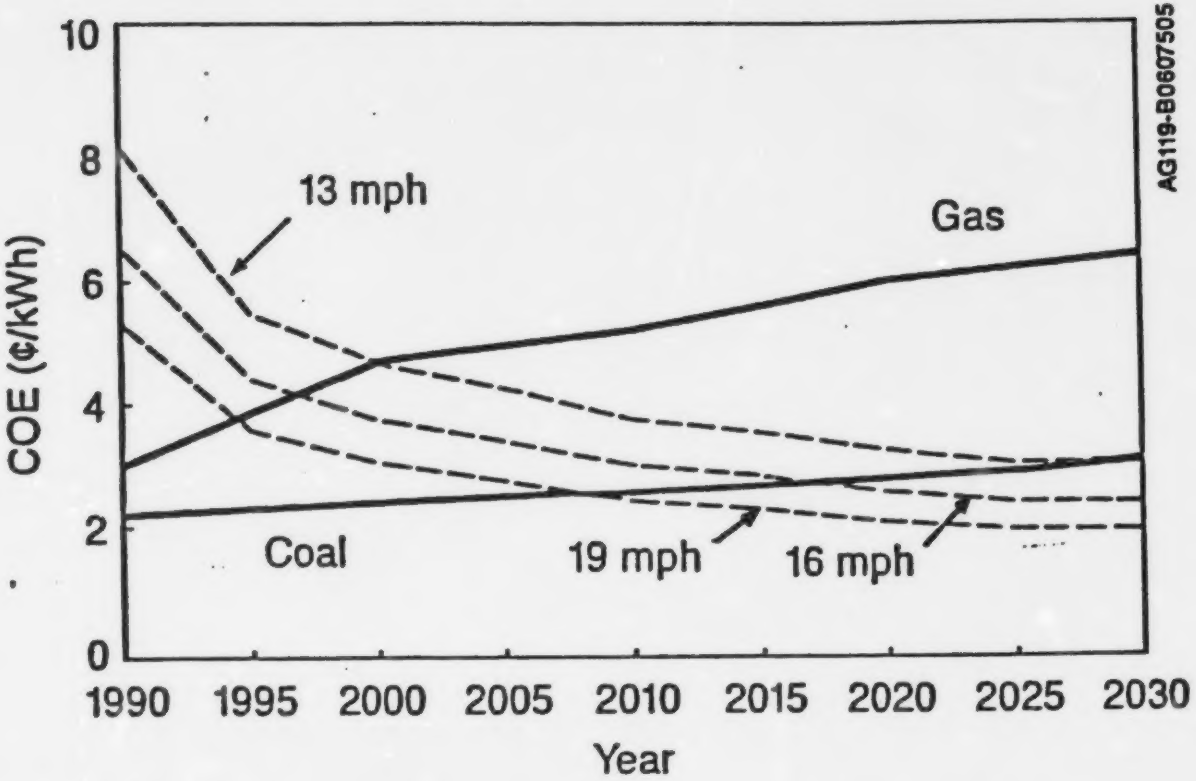
adwindhg34

Advanced Wind Turbine Development Goal:

To support industry efforts to incorporate advanced wind turbine technology into the marketplace in the near-term (1993-1995) and to provide the next generation of advanced wind turbines for the mid-term (late 1990's).

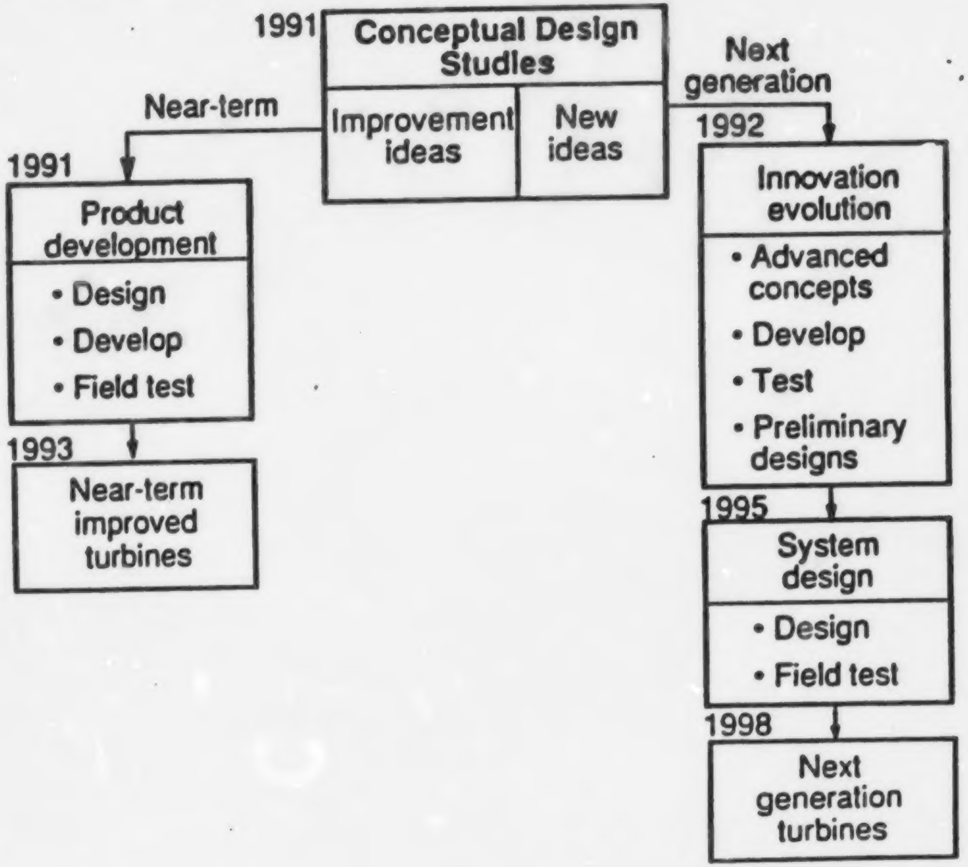
shgoalhg35

WIND ENERGY COE ESTIMATES AS A FUNCTION OF WIND SPEED



SERI

Advanced Turbine Development Program



1991 Conceptual Design Studies

- Improvement ideas
- New ideas

Near-term

1991 Product development

- Design
- Develop
- Field test

1993 Near-term improved turbines

Next generation

1992 Innovation evolution

- Advanced concepts
- Develop
- Test
- Preliminary designs

1995 System design

- Design
- Field test

1998 Next generation turbines

P17 C07236028

Conceptual Design Studies

Objective

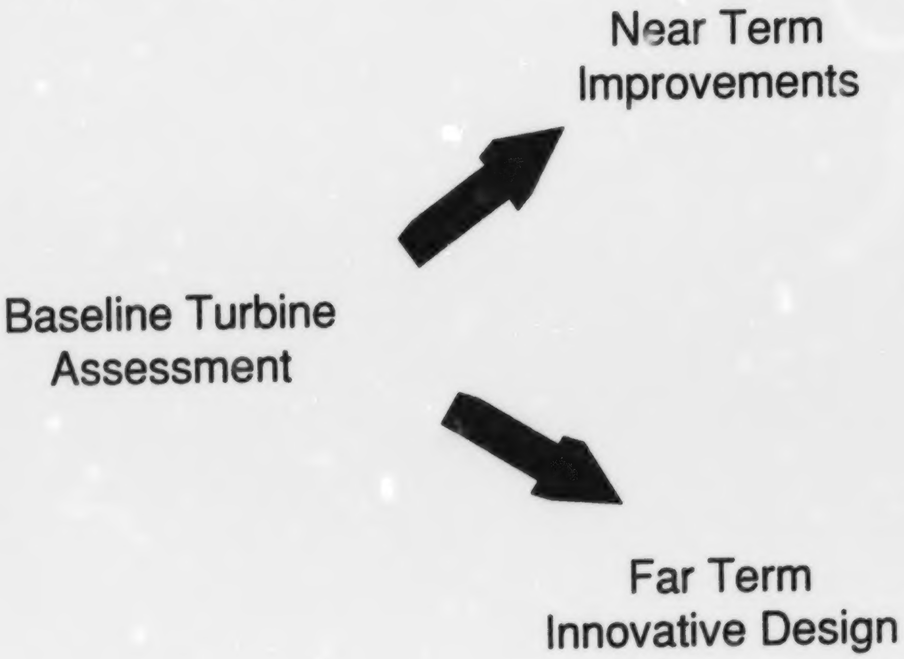
To Study:

1) Conceptual designs integrating state-of-the-art improvements to existing wind turbines for 1993-1995

2) Conceptual designs for innovative wind turbines for 1998-2000

condesighg34

Conceptual Design Studies Approach



Baseline Turbine
Assessment

Near Term
Improvements

Far Term
Innovative Design

condesaphg35

Conceptual Design Studies

Key Activities

Atlantic Orient Corp.
Enertech 44

- Two bladed teeter hub vs. Three-bladed rigid hub
- Advanced airfoils
- Increasing rotor size
- Increasing rotor height
- Improved yaw control
- Adaptive turbine control
- Tower material review
- Variable speed operation

Northern Power Sys.
North Wind 100

- Yaw system review
  - upwind vs. downwind
  - controlled vs. passive
- Rotor system review
  - hub design
  - teeter joint design
  - delta-3
- Variable speed operation
- Increasing turbine size
- Advanced airfoils

'R. Lynette & Assoc.
ESI - 80

- Incremental Improvements
  - tip brake improvements
  - teeter bearing design
  - teeter damping
  - structural improvements
  - improved control
  - other specific items
- Value engineering
- Adaptive turbine control
- Increasing turbine size
- Advanced airfoils
- Varible speed operation
- Increasing tower height

LOGOCONhg35

Near-Term Product Development

Objective

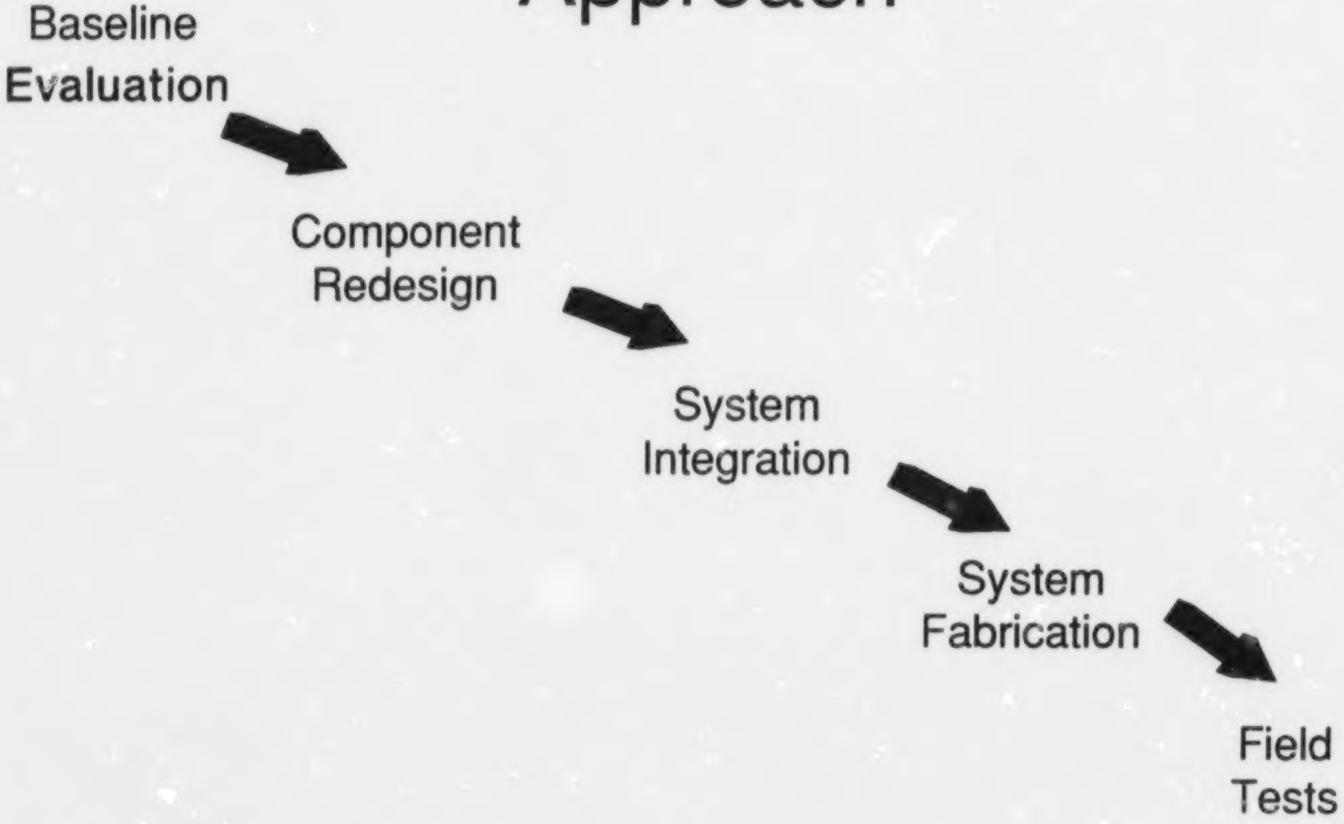
To assist industry to rapidly develop AWT systems
for the 1994-1995 near-term utility market

Cost Goal
$.05\KWh at 13 MPH sites

Benefits
Minimize cost, risk, and development time
Increased competitiveness for U.S. industry in the near term
Regional diversification

near devhg35

Near-Term Product Development Approach



Baseline Evaluation

Component Redesign

System Integration

System Fabrication

Field Tests

Prod Devhg35

Next Generation Technology Development

Objective

To assist industry to develop innovative utility grade, next generation wind turbine systems that will be commercialized in the 1998-2000 time frame.

Cost Goal

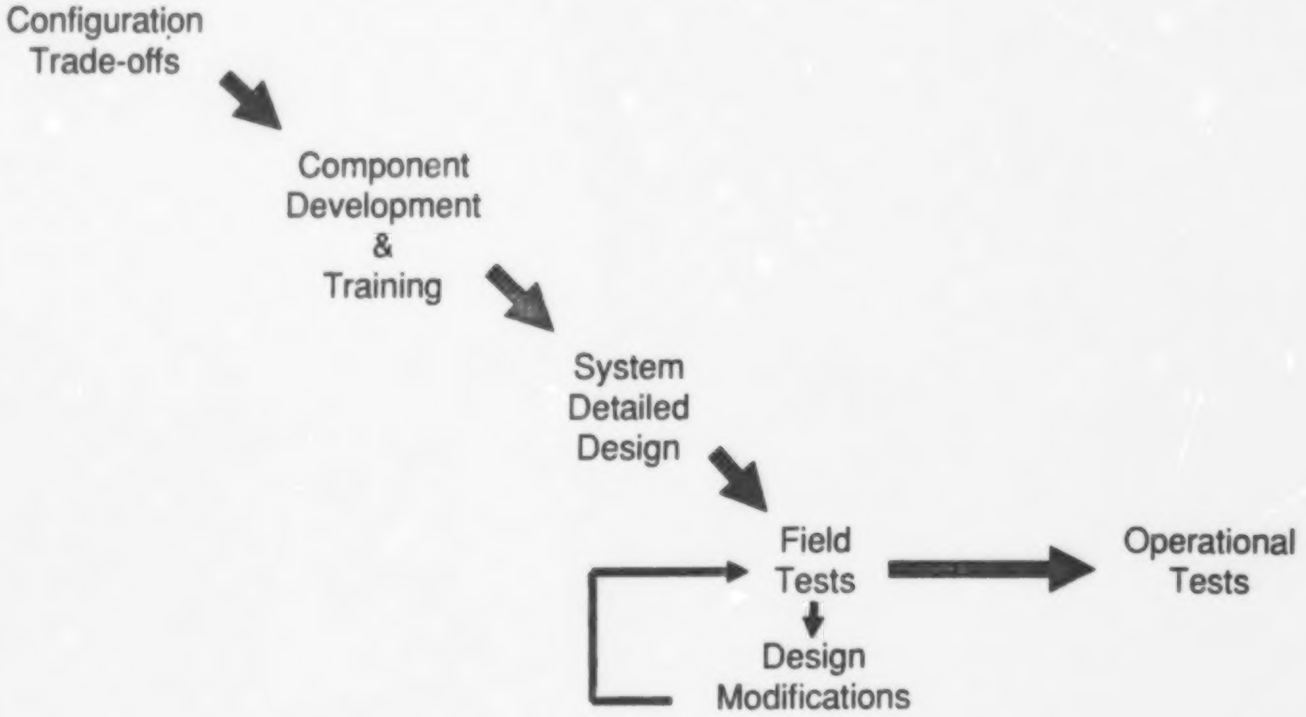
$.04\KWh at 13 mph sites.

Benefits

Increase utility participation and acceptance.
Increase industry stability and strength.
Maximize design innovation.

nextgenhg35

Next Generation Technology Development Approach



Configuration
Trade-offs

Component
Development
&
Training

System
Detailed
Design

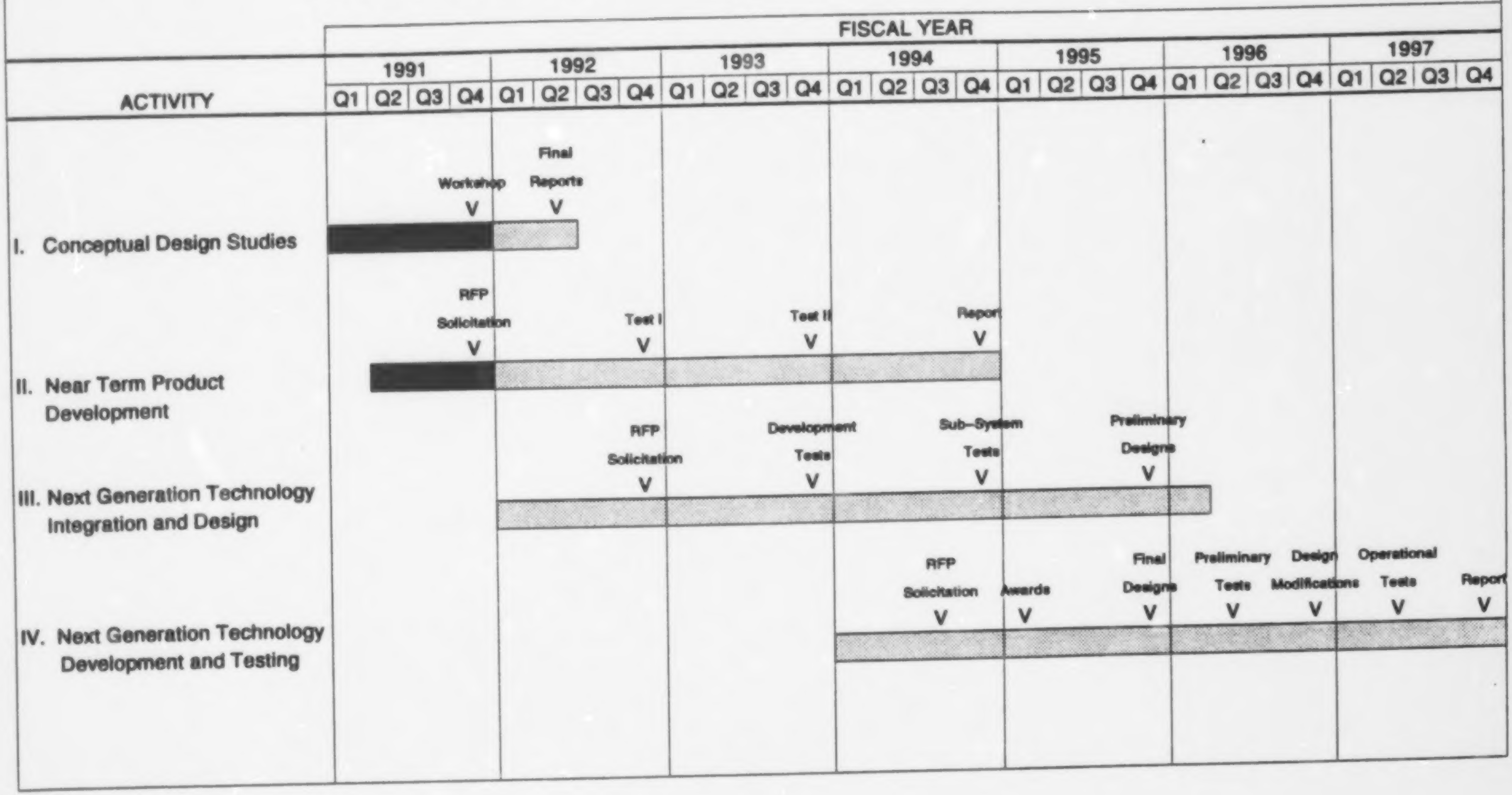
Field
Tests

Design
Modifications

Operational
Tests

nextgenthg3~~4~~5

ADVANCED WIND TURBINE DEVELOPMENT PROGRAM



DETAILED DESIGN OF A 24m DARRIEUS ROTOR WIND TURBINE

D.J.Malcolm
David Malcolm Associates Inc.

ABSTRACT

This paper presents the background and objectives of a detailed design study carried out by LavalinTech Inc. on behalf of Energy Mines & Resources as part of the Federal Panel on Energy Research and Developement. The rationale for the design of all major components is presented together with estimates of the energy production in various wind regimes. The paper covers the entire wind turbine - rotor, drive train, support system and controls.

1. INTRODUCTION

In 1969 the Darrieus rotor was rediscovered by staff of the National Research Council of Canada. A development programme was initiated which involved prototypes of increasing size, culminating in the 4000m^2 machine "EOLE" now owned and operated by LavalinTech at Cap Chat in the Gaspe region of Quebec. Project Eole demonstrated the abilities of Canadian engineering and has attracted worldwide attention. However, it has been recognized that such large machines may not be as cost effective as smaller ones because of the effect of scale on the cost of major components (1).

LavalinTech undertook a feasibility study for machines of smaller capacity (2) and concluded that even a 1 MW-rated machine was not cost-effective without several advances in technology. It also concluded that progressive improvement in existing, proven designs was the fastest way to arrive at a commerially viable design. These findings were in keeping with trends found elsewhere in the wind energy industry where rotors having diameters between 20 and 25 metres have been found to be the most cost-effective at present (3).

2. OBJECTIVES

The overall purpose of the project carried out by LavalinTech was to use the best features from machines such as the FloWind 19m and the Indal 6400 and to use recent airfoil advances to arrive at a cost-effective and reliable design. In summary the project had the following objectives.

1) To use existing 6061-T6 aluminum extrusion technology to produce a blade with a high fatigue strength;

2) to use the largest single extrusion blade possible and to

maximize the swept area;

3) to use tailored airfoils to reduce the rated power of the machine and to mimimize drive train costs;

4) to use new techniques for inexpensive blade connections with high fatigue strength;

5) to mimimize the weight of the rotor and to simplify all fabrication details;

6) to design a drive train which uses standard, off-the-shelf items for mimimum cost and ease of maintenance;

7) to use commercially available components for the control system

8) to be able to transport all components by road without requiring a special permit;

3. PERFORMANCE

The overall objectives of any wind energy project must be to extract the maximum energy for the least total cost. The use of cost per kw capacity, or energy extracted per unit swept area may not always be meaningful especially when comparing different types of machines.

It was recognized that the design and cost of all components are inter-related and that it is the total cost that is important. It was considered necessary, therefore, that the drive train cost be mimimized, which led to the use of a high rotor speed and airfoils that will induce early stall and will lower the maximum torque.

The projected electrical performance curve is shown in Figure 1 and is based on the following assumptions.

rotor speed	50rpm
rotor diameter	24m
no. of blades	2
chord	0.737m (constant)
airfoil	SNLA1850
air density	1.225kg/m^3
drive train loss	10kW + 10% of aero power
swept area	488m^2

Using this performance curve the following annual energy productions were predicted (based on 100% availability, a Weibull distribution with a shape factor of 1.6, and a high wind cut-off of 20m/s)

TABLE 1

Annual Energy Production

mean annual mid-rotor windspeed m/s	annual energy production MWh/yr	annual energy per swept area kWh/m^2
5	209	428
6	340	697
7	470	963
8	575	1178
9	660	1352
10	720	1475

- standard sea level conditions
- 100% availability
- Weibull shape factor = 1.6
- high wind cut-off = 20 m/s

4. DESIGN DETAILS

The general arrangement of the rotor is shown in Figure 2 and that of the drive train in Figure 3. Full details of all components will not be shown in this paper due to their proprietary nature.

4.1 Natural Frequencies

Several of the components of Darrieus rotors are governed by stiffness rather than strength requirements. Examples are the central column and the guy cable restraints. The size of those components was reduced and the corresponding natural frequencies were allowed to fall as much as was compatible with structural integrity.

The relationship of the first twelve natural frequencies with rotor speed is shown in Figure 4. It shows that there is a window which includes the 50 rpm operating speed and up to a 20% overspeed.

4.2 Central Column and Weldments

The column is a single thin-walled steel tube (outside diameter 1117 mm, 43 inches), since such members are available from many sources, either spiral welded or brake formed. A single mid-height field splice is included so that parts can be easily transported by road.

The conical sections at each end are aimed at facilitating the connection to the blades and to the upper and lower bearings. The upper and lower weldments are nearly identical and consist of a minimum number of parts.

4.3 Horizontal Struts

Horizontal struts are included for structural reasons. The constant chord blade would not be sufficiently strong to span the full height of the rotorwithout support. Tapered chord blades have been proposed but are not yet cost-effective. The location of the struts has been chosen to minimize aerodynamic drag while still fulfilling their structural purpose.

For greatest stiffness-to-weight ratio a trusss configuration is desirable for the strut. However, a laterally stiff strut tends to concentrate blade forces at that location and a more flexible strut is preferred. A solution, similar to that used in the Indal 6400, was adopted by specifying a single standard I-beam with suitable fairings.

The I-beam passes through holes in the column and requires only straight-forward connections and stiffening.

4.3 Blades and Connections

There are three types of blade connections: the root connections, blade-to-blade splices, and the connection to the horizontal struts. It was decided to make the first two as similar as possible, to standardize parts, while the third was made as simple as possible.

The critical problem in past root and splice connections has been the fatigue strength of the aluminum in the vicinity of the mechanical fastener holes. This is partly due to the surface fretting caused by movement allowed by the fasteners. The ideal solution might be to design a purely bonded joint but that technology is not yet adequately proven. Another solution is to use fasteners which fill the hole and minimize the relative movement and to induce compressive residual stresses around the hole. Aircraft manufacturers have for some time used the latter techniques but the cost per fastener has been high.

In this project we attempted to adapt a less expensive commercial fastener, the Huck BOM blind bolt, to aircraft techniques. The principal steps in the procedure are:

- bend the aluminum/stainless steel doubler plates to the contour of the airfoil;
- install temporary 1/4" bolts tapped into the blade;
- on site drill and ream the holes in the doublers and the blade

to the exact diameter;

- cold work the holes by pulling a suitable mandrel through the holes;
- insert the blind fastener and its guaranteed tensile load.

To confirm the fatigue strength of this connection and to compare with the strength of other fasteners, a series of fatigue tests was carried out. The results of the tests are summarized in Figure 5 which shows that the proposed system is indeed superior to previous designs. The results confirmed that the inclusion of cold working of the holes is advantageous. It was not so certain that the aircraft-type sealant included between the faying surfaces was equally beneficial.

The design of the strut to blade connection followed the principles used on the Indal 6400 - a mechanical hinge to negate in-plane bending, and two high strength stainless steel bolts that pass through the blade which has been reinforced with several additional sheets of bonded aluminum. However, the design was thoroughly reviewed for simplifications and cost savings. This was acheived by standardization of parts and by reducing the amount of machining required.

It is important that the blade curve closely follows the true troposkein shape (to mimimize the in-plane bending due to centrifugal forces). A special computer program calculated the location of standard kinks to achieve this shape. The manufacturer can, therefore, merely mark the approximately 160 locations on the initially straight blade and proceed to apply the same bulldozer deformation at each.

4.4 Guy System

The guy system is a traditional one with three pairs of 1 1/8" cables at 35 degrees to the horizontal. However, the details of the upper head connection have been simplified and the size and preload of the cables has been kept to a minimum (the same as are used on the FloWind 19m rotor).

4.5 Bearings

The two-bearing upper system has been kept as compact as possible to mimimize eccentricities and associated loads. It consists of a set of grease lubricated radial bearings and a spherical roller thrust bearing. The bearing assembly is separate from the upper weldmenta and the two are bolted together on the site.

4.6 Drive Train Configuration

Considerable thought was given to the best configuration of the drive train. Options included a high-speed brake vs. a low-speed brake, a parallel vs. a right-angle gear box, and a grease vs. an oil lubricate bearing.

The final configuration selected is shown in Figure 3. It was decided that there was little difference in the cost of the two possible brake locations since the greater cost of the low speed brake was balanced by the greater service factor required for the gearbox.

The combination of a parallel shaft gearbox with a flange-mounted induction motor was the most compact and least expensive and also allowed a smaller enclosure and better access for maintenance.

The mounting of the major components at ground level is consistent with the traditional advantage of all Darrieus machines but it does result in a 3.3m long low-speed shaft and two couplings. These, however, result in torsional softness which attenuates any torque ripple in the drive train and allow the use of a single lower thrust bearing (which can tolerate the limited movement of the rotor).

The enclosure is an extremely simple steel frame which involves no on-site welding and only standard high strength bolts. It is tapered so that the weight of the platform supporting the lower bearing can be minimized. This enclosure and support is shown with a height of 5.0m; this could be increased without much expense to 10m or 15m in locations where the greater mid-rotor windspeed justified this change.

4.7 Braking System

The low speed mechanical brake is the only system for stopping the rotor and it is important that it be fail-safe. It was, therefore, located above the lower bearing and directly on the lower stub shaft (as is done by FloWind).

Braking can be carried out by either one of two independent pairs of spring-applied hydraulically released floating calipers. Only in an emergency condition are both pairs of braking systems applied (such as a grid failure or an overspeed condition). Under normal conditions the two systems are used alternately so that wear on each is equal and any failures become apparent.

4.8 Control System

The control system comprises a commercial Klockner Moeller PS3 programmable logic controller (PLC) operating through an autosynchronous controller (ASC). The second device has been applied recently to a number of machines in California and is a patented product of its American manufacturer, ENERPRO.

The ENERPRO ASC brings a number of valuable qualities to the wind turbine operation. It works by employing silicon controlled rectifiers (SCR) which, by controlling their firing angle can permit only a fraction of the voltage waveform on the line to develop in a given cycle. It has five different modes:

1. Reduced voltage start. This avoids the possible high starting torque or the need for separate reduced voltage starter.
2. Soft contact as the rotor speed passes through sychronous speed. Bringing the motor on line at exactly the right moment has been a problem until now.
3. Low power energy saving. Lower voltages when the wind power is low results in lower motor losses.
4. Over-running clutch. This allows the rotor to coast without torque changes as the speed varies and the generator contacts are switched on and off.
5. Generator winding heater. When the machine is idle a small current can be allowed to pass and to warm the motor and prevent condensation from collecting.

5. COSTS

The costs of most components and assemblies were obtained from quotes or were estimated and an approximate total cost was identified. However, these costs were not necessarily the lowest and were obtained for a limited production of four machines. In addition the costs of shop and field assembly and of installation have not been fully analysed.

The following breakdown of component costs was obtained.

Rotor		
Blades and connections	15%	
Column and weldments	15%	
Anchors	10%	
Struts	5%	
Bearings & housings	5%	
Guy cables	5%	55%
Drive Train		
Gearbox	14%	
Brakes	10%	
Structure & foundations	8%	
Motor	4%	
Low speed shaft & couplings	4%	
Controls & switchgear	5%	45%
Total		100%

The total cost of the manufactured machine (for a prototype production of four) was estimated at approximately $200,000CDN in 1991. In larger numbers this cost should be reduced by at least 20%.

The final cost of energy depends on many additional factors such as interest rates, wind regime, interconnection costs, land costs, etc. However, one criterion used in the U.S. industry is the installed cost per annual kWh produced, which should not exceed about $0.40. In a wind regime with an average speed of 8.0 m/s, the L24 cost would satisfy this criterion.

6. SUMMARY

The design presented in this paper is considered to be a cost-effective Darrieus rotor wind turbine for these reasons.

- the design uses largely known technology and attempts to improve upon existing, tested designs;
- the design aims to stretch to the limit the abilities of current technology of single aluminum extrusion airfoils;
- the ratio of total rotor weight to swept area is lower than all existing machines of this type;
- the performance and energy output is comparable to a typical 23m diameter horizontal axis machine;
- throughout the design the manufacturability has been considered. This has led to the reduction in the number of different parts and in the extent of machining;
- the new blade connections are simple and have demonstrated their superiority in fatigue tests.

The design is the property of the federal government of Canada and represents a culmination of many years of research and development in Canada. It offers a possibility to Canadian industry and an opportunity of diversification to some of the regions blessed with more vigorous wind regimes.

7. REFERENCES

1. D.J. Malcolm, "Feasibility of Large Scale Wind Turbines", Proceedings of Canadian wind Energy Conference, Banff, Alberta, Oct. 1990.

2 "Development of a Second Generation Large Vertical Axis Wind Turbines. Phase 1, Final Report", LavalinTech Inc. on behalf of Supply and Services Canada, Contract 23283-8-6070, April 1990.

3. J.P. Molly,"Maximum Economic Size of Wind Energy Converters". Proceedings EWEC 89, Glasgow, July 1989

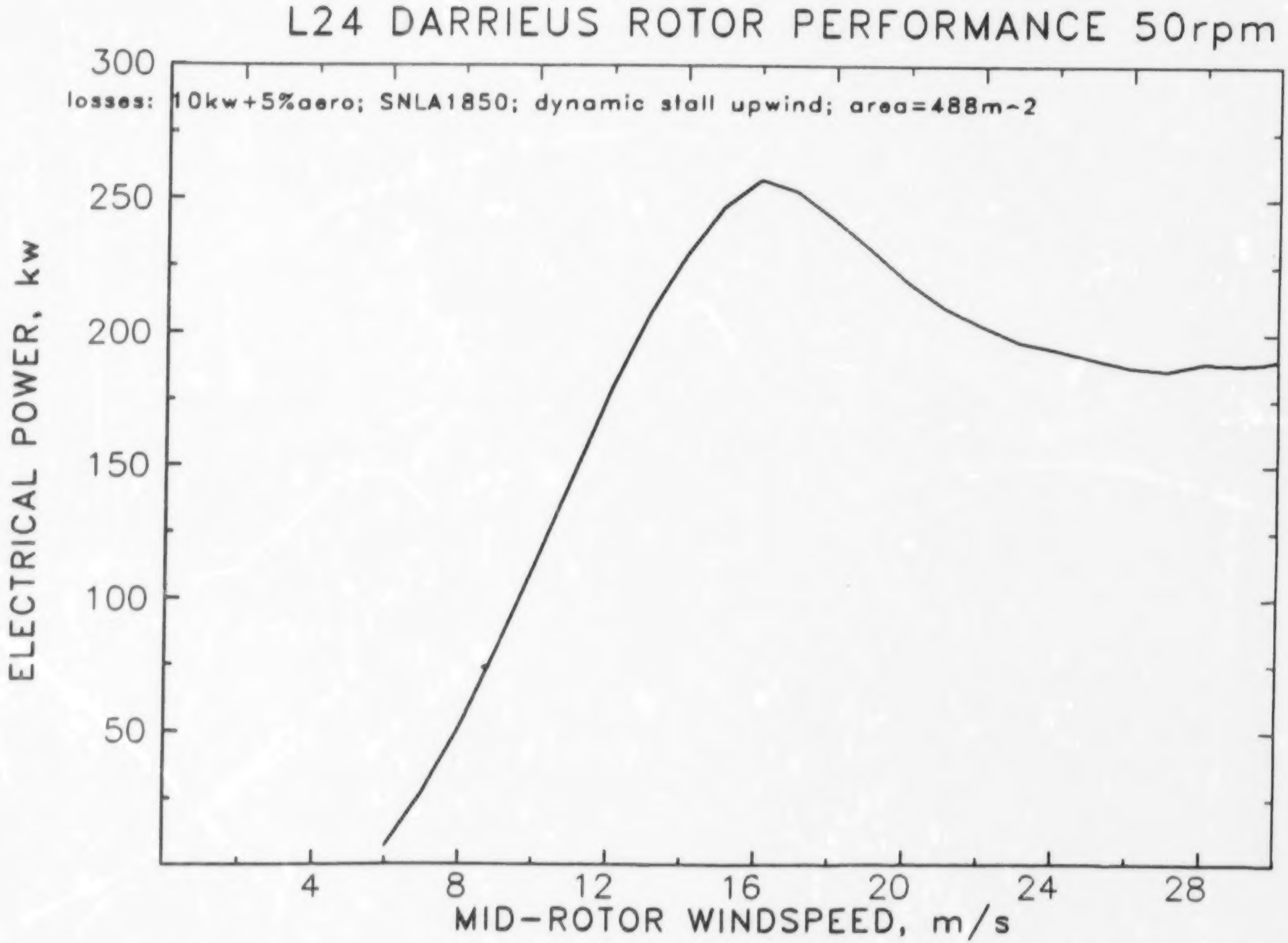
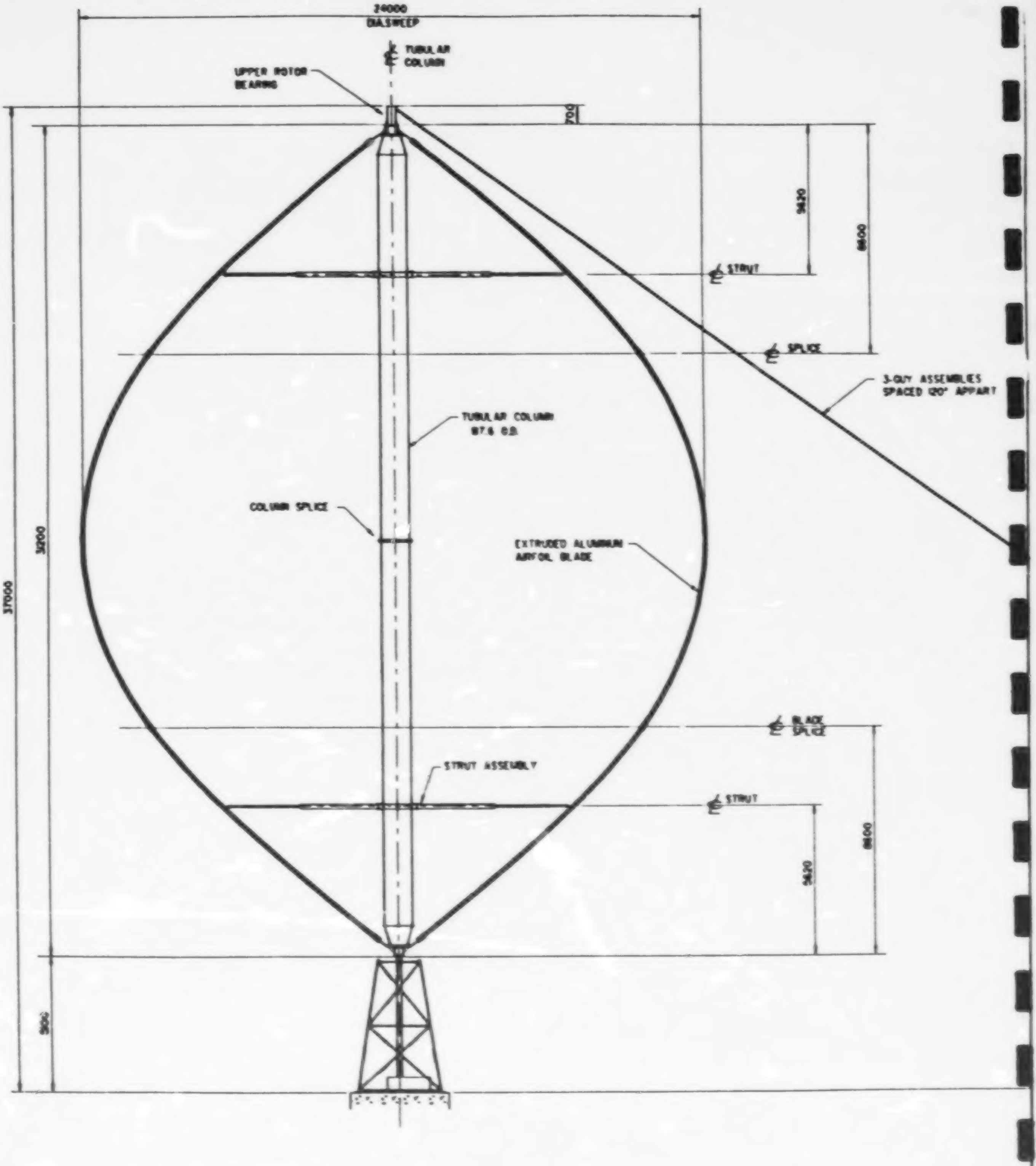


Figure 1. Predicted Electrical Performance of L24 Wind Turbine


24000
DIA.SWEEP
℄ TUBULAR COLUMN
UPPER ROTOR BEARING
700
3420
8800
℄ STRUT
℄ SPLICE
3-GUY ASSEMBLIES SPACED 120° APPART
TUBULAR COLUMN 87.6 O.D.
COLUMN SPLICE
EXTRUDED ALUMINUM AIRFOIL BLADE
31200
37000
℄ BLADE SPLICE
STRUT ASSEMBLY
℄ STRUT
8800
3420
5100

24m DARRIEUS ROTOR WIND TURBINE

LAVALINTECH INC

Figure 2. General Arrangement of L24 Rotor

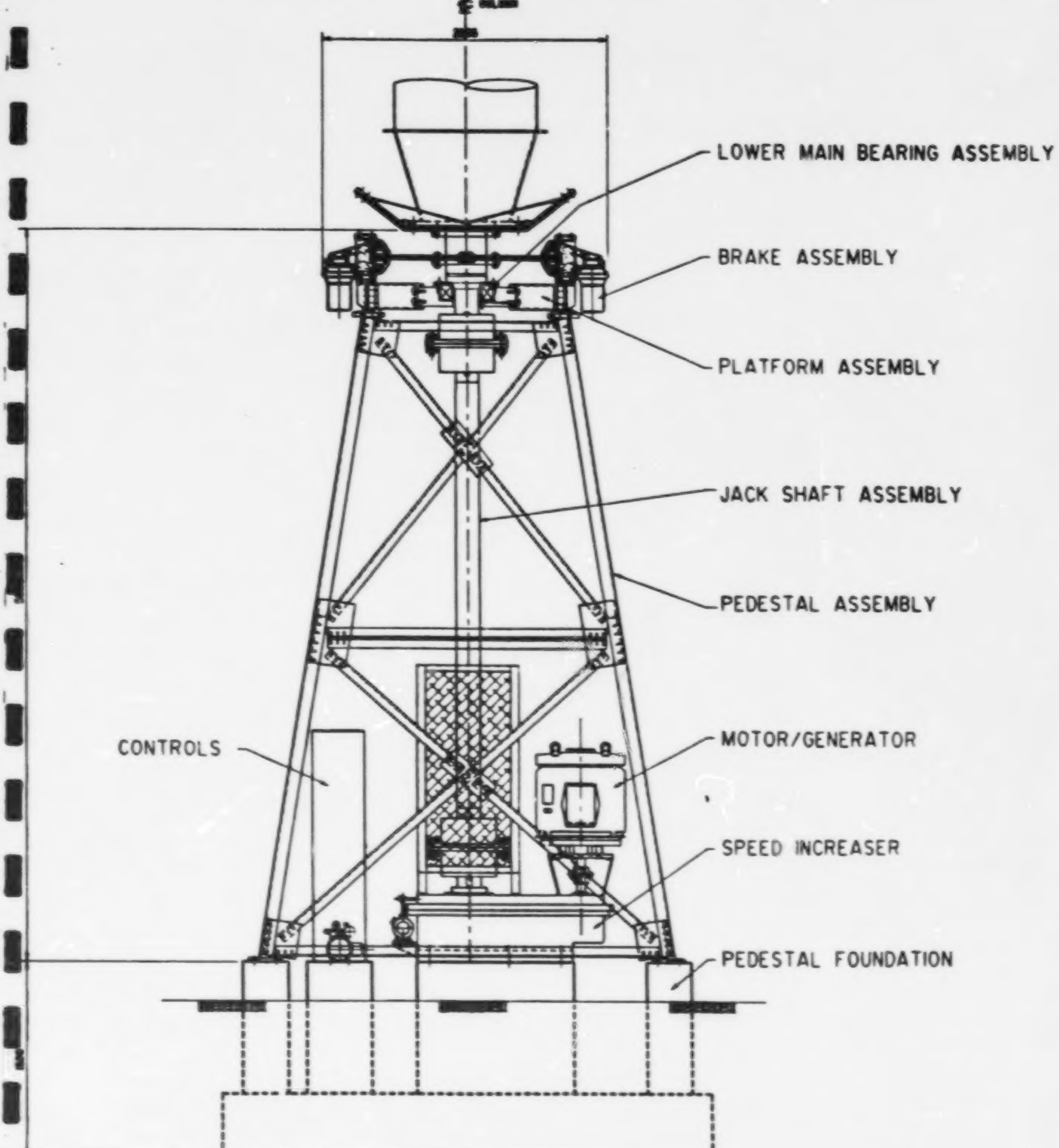

LOWER MAIN BEARING ASSEMBLY
BRAKE ASSEMBLY
PLATFORM ASSEMBLY
JACK SHAFT ASSEMBLY
PEDESTAL ASSEMBLY
CONTROLS
MOTOR/GENERATOR
SPEED INCREASER
PEDESTAL FOUNDATION

Figure 3. General Arrangement of Drive Train for L24

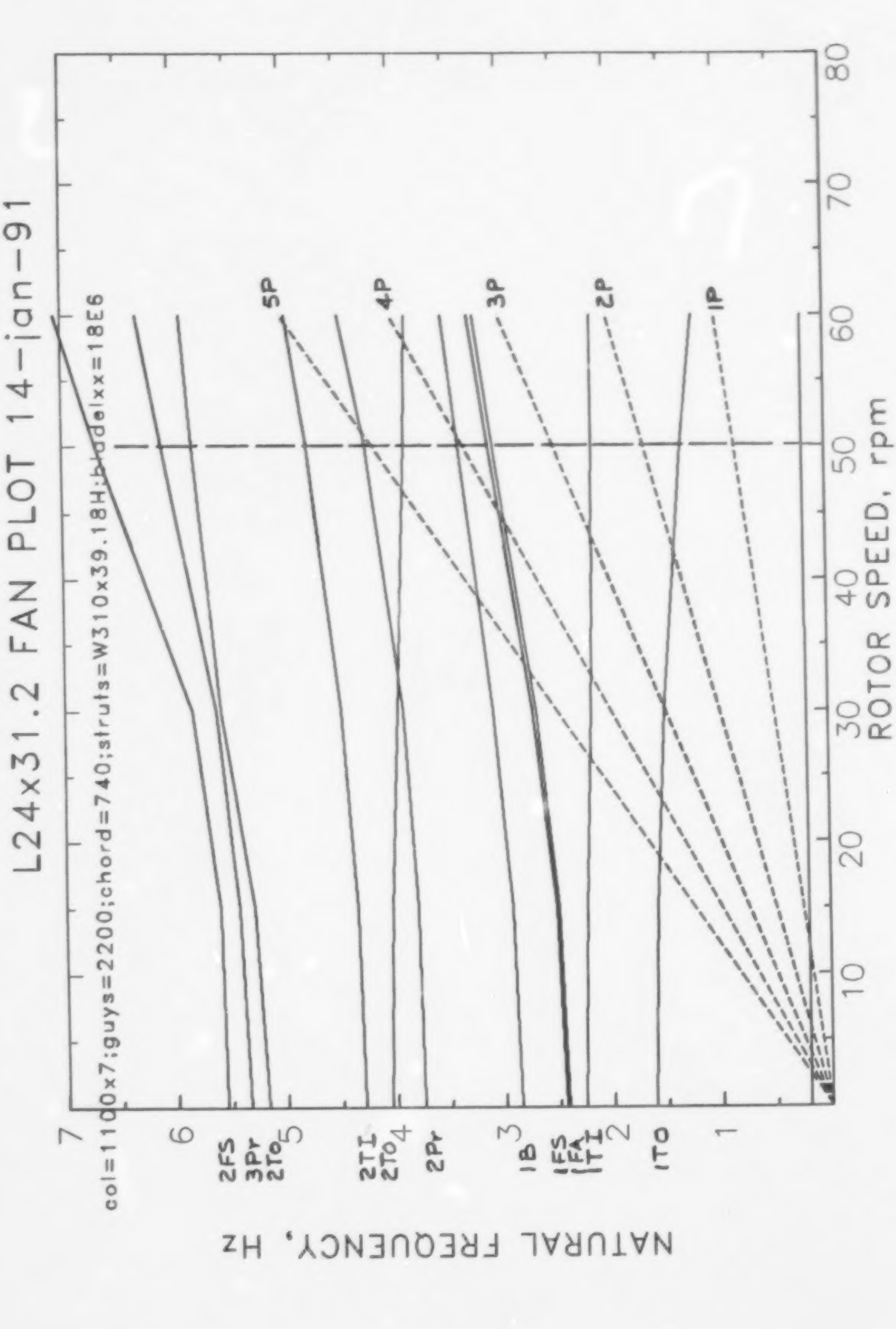


Figure 4. Natural Frequency vs. Rotor Speed for L24

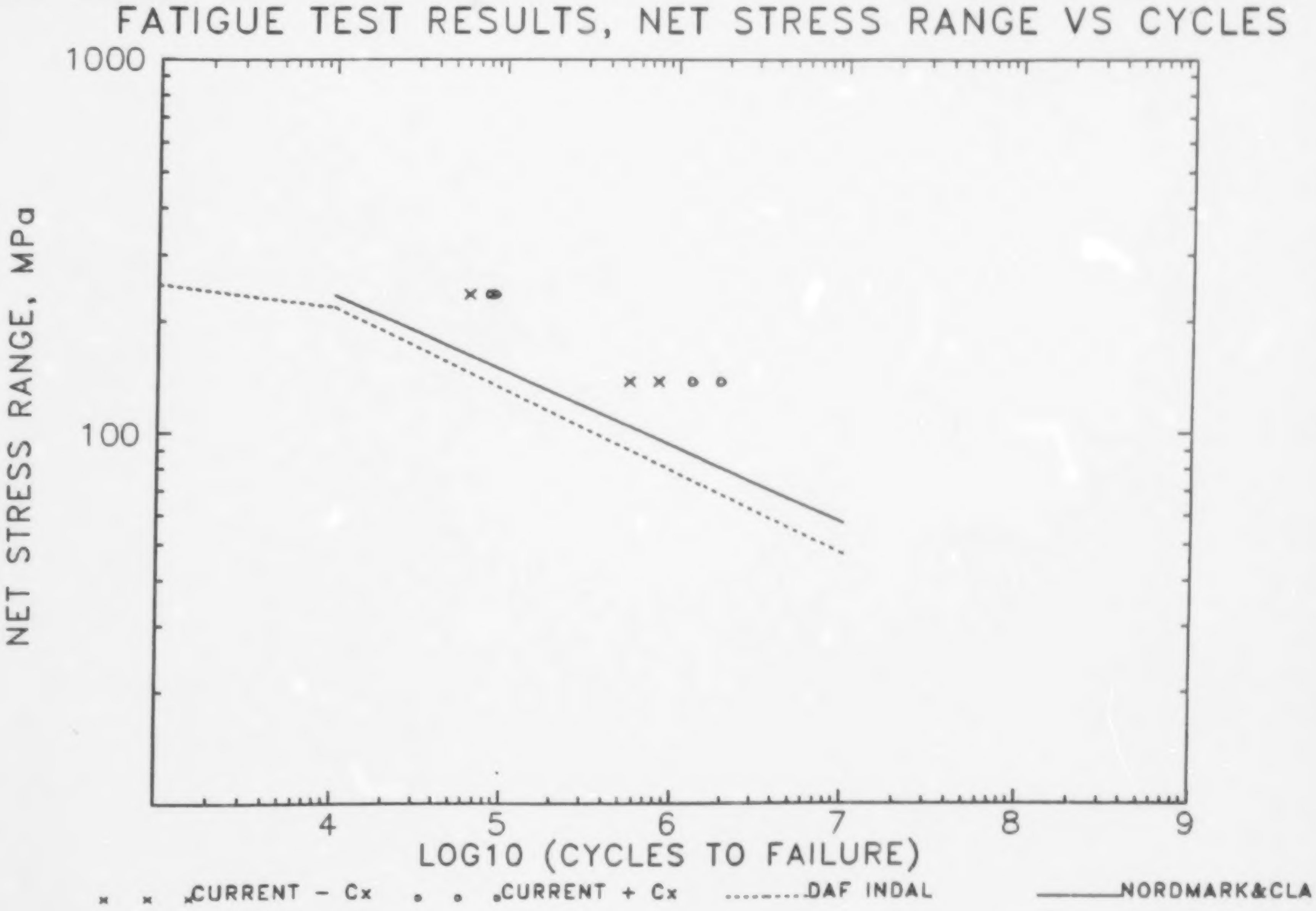


Figure 5 Fatigue Test Results and Comparison

→ Malcolm
10 June '9

NORTHERN POWER'S
ADVANCED WIND TURBINE DEVELOPMENT PROGRAM

Presented by Clint (Jito) Coleman
NPS, Moretown, Vermont, USA

September, 1991

Abstract:

NPS was selected by SERI to participate in the Advanced Wind Turbine Development program which was begun in 1990. NPS' concept was based upon the North Wind 100 wind turbine which operated in Altamont Pass and was extensively tested by NPS/SERI under the Cooperative Field Test Program during the wind seasons of 1987 and 1988.

NPS has successfully completed Task 1 and Task 2 reviews for this contract during the first half of 1991. Task 1 and 2 focused on redesign of the baseline turbine to obtain the design concepts, performance and cost predictions for an Improved Design Concept. The remaining activity under the contract will be to develop an Advanced Design Concept which is due to be completed by the end of 1991.

NPS has incorporated new technological innovation in the turbine rotor. The Improved Concept embodies aileron control surfaces for rotor control, an advanced teetering control system, an innovative blade structural concept. The drive train and electrical generation components have been refined and improved to provide lower initial cost and lower annual O&M requirements. The results of the design process has yielded an extremely competitive turbine for wind farm applications.

Project Summary:

Under the Advanced Wind Turbine Conceptual Design Contract, NPS has carried out Task 1 and Task 2. These tasks were layout to provide a comprehensive review of the baseline turbine and make changes to the baseline turbine based upon the analysis.

Task 1 activities included:
    Key Area Analysis
    Summary of Test Data
    Potential Improvements List
    Improved Turbine Concept and Value

After the Task 1 report was presented to SERI, selected Improvements were selected for further study and detailed engineering analysis.

Task 2 activities were aimed at taking these selected improvements, integrating them into the turbine, evaluating their effectiveness, and drawing conclusions as to the overall turbines energy production, production cost, O&M cost and cost of energy, as well as the evaluation other Factors of Merit. The specific technical areas of the turbine which were extensively explored within Task 2 were:

- Flow-Through laminated Wood Blade
- Aileron Control (utilized as a Drag Brake)
- Teeter System

These three areas of concentration are all ultimately related to the turbine rotor system, which was shown to be the element where: the most cost effective changes could be made, the largest increase in energy capture could be obtained, both mean and cyclic load reductions could occur, where turbine downtime due to unscheduled maintenance could be improved, and the turbine overall O&M requirements could be reduced.

NPS utilized an array of computer simulation programs to verify the loads and performance of the rotor, as well as finite element structural codes to review the stress and deflection of the rotor. The quasi-steady state aerodynamic loads and performance were analyzed with PROP. The operational loads analysis were reviewed using the FLAP code and the OSU structural dynamic code. To validate the models, NPS correlated the PROP output, and FLAP code predictions to 100 kW field testing data sets. In this manner the inputs, methods, and results were all *physically* related to the results from the 100 kW test program. This approach clearly allowed for the development of the new rotor system as an improvement over the 100 kW configuration.

Flow-Through Laminated Wood Blade

The rotor system consists of a laminated wood D-spar which runs from blade tip to blade tip as one single structural element. The trailing edge elements of the blade are either deployable ailerons on the outboard 30% of the span or non-deployable plastic sections on the inboard sections. The rotor to hub interface provides a load path for the rotor thrust and torque loads to the drive train, as well as teeter control. The other loads inherent in the rotor remain in the rotor and do not pass into the hub. This improved load path will yield a significant reduction in part weight and simplicity in component design.

Aileron Control

The use of ailerons as the primary control surface was particularly attractive to the design team. While NASA Lewis did extensive design and field testing of the concept no commercial turbine has ever used the aileron. The aileron concept provides an effective aerodynamic control surface on the rotor which is as effective as any currently utilized tip mechanism or pitchable tip. The advantage is that the loads are significantly less, the aileron can be used to modify basic aerodynamic properties of the rotor, as well as provide controllable shut down.

Teeter Control System

The teeter control system was envisioned to provide the following control capabilities:

- Teeter Locking or Braking from 0 to 50% rated RPM
- Varying Teeter Stiffness vs Teeter Angle
- Moderate Teeter damping at moderate to high teeter angles
- High damping at the end of stoke

NPS is patenting the teeter control system which is currently being designed and developed under this program.

Improved "Near-Term" Turbine Configuration

Rotor
    70 ft Diameter (21.34 meters)
    60 RPM
    Upwind, 2 Bladed
    Teetered Hub with Teeter Control Subsystem
    Flow Through Blade Structure
    Aileron Control Surfaces

Blades
    Laminated Douglas Fir
    SERI Advanced Airfoils
    D-Spar Structural Member, Tip to Tip
    Molded Plastic Aft Body Parts

Gearbox
    25 : 1 Helical
    Shaft/Flange Mounted
    Integral Generator Mount

Generator
    150 kW Induction, Single Generator
    Constant Speed 1800 RPM
    Capacitive Compensation

Yaw Assembly
    King Pin Layout
    Friction Surface Turntable Bearing
    Electrical/Mechanical Yaw Drive

Tower
    150 ft Guyed Steel Tube
    Tiltable

Economic Evaluation and Figure of Merit

NPS' conclusion is that the Advanced Turbine may be a significant breakthrough in both performance and cost of energy. The combination of a low weight turbine and high performance, tailored specifically for an energetic Great Plains site, will make this configuration a very promising choice for utility planners in the near future.

The Proposed Sale Price of the Improved Turbine into Wind Farm environments is approximately $100,000. The turbine's on tower weight is 3,748 kg (8,247 lbs), represents a significant improvement over the North Wind 100 weight of 4,818 kg (10,600 lbs). The majority of the weight saving comes from the new rotor configuration.

For sites identified as the Great Plains, by SERI, NPS has estimated the turbines performance and cost of operations. Tables 1 provides a breakdown of the anticipated wind farm costs and performance for the turbine. Table 2 uses this information to calculate the COE from a 50 megawatt wind farm.

The Great Plains COE of 3.54 ¢/kwhr is very exciting. The goal of the program was 5¢/kwhr. The analysis and assumptions that went into the calculation of this value are fully described in Tables 1 and 2.

The financial assumptions used in this analysis have been provided by SERI to establish a level playing field. It is not certain at this time if the financial community will agree to these economic assumptions. In any case, this Improved Turbine would provide a very attractive return.

The California wind farm site, a calculated COE of 6.22 ¢/kwhr is substantially higher due to the lower wind speeds at these site, 14 mph annual average, with a tower height of 80 ft. With an installed cost of the turbine in California of $750/kw, some wind farm operators estimate 5¢/kwhr power is realistic. Again wind speed distribution, mean wind speed and the financial assumptions all influence this final COE value.

Table 3 provides another method of looking at the turbine in comparison with the North Wind 100 and the Bonus 120. This table provides other Figure of Merit which have been applied to wind farm turbines. This is another method of estimating their relative effectiveness and market potential. As is shown in this Table 3, the Improved Turbine has realized significant advances over the North Wind 100 and out performs the Bonus 120 in many significant areas. Of particular interest is the annual kwhr/pound comparison, where the Improved Turbine is almost three times better than the current best Danish design. Given these economic and engineering advances, the Improved Turbine could provide a real and significant opportunity for the Near Term Market.

TABLE 1: GREAT PLAINS WIND FARM SYSTEM FINANCIAL SUMMARY

	PER UNIT		50 MW FARM 330 UNITS TOTALS	
TURBINE	$81,073			
TOWER: 150 FT	$20,025			
TOTAL	**$101,098**		**$33,362,340**	
BALANCE OF STATION COSTS				
FOUNDATIONS	8500	$2,805,000		
ROAD AND FENCES	700	$231,000		
ELECTRICALS	9700	$2,880,900		
INSTALLATION EQUIP.	3200	$1,056,000		
CONTROL AND MONITORING		$250,000		
MAINTENANCE FACILITIES		$400,000		
INITIAL SPARES	4%	$1,070,164		
		TOTAL	**$8,693,064**	
TOTAL INSTALLED COST: ICC			**$42,055,404**	
		ICC/KW	**$850**	
ANNUAL O&M				
MAINTENANCE: BURDENED PERSONNEL		$624,000		12 FULL TIME PEOPL
PARTS	2%	$535,082		
INSURANCE COSTS	2%	$267,541		
OTHER COSTS		$100,000		
LAND COSTS 4 A/ TURBINE	1320 A	$264,000		5D X 10D SPACING
TOTAL		**$1,790,623**		
RETROFIT COSTS OVER 30 YEARS				
AILERON REPAIR: 8 YEARS	$2,100	$693,000		
YAW DRIVE: 10 YEARS	$2,500	$825,000		
OTHER: 20 YEARS		$1,000,000		
ENERGY ANALYSIS				
ENERGY	591,285 KWHRS/YR/TURBINE			
LOSSES				
AVAILABILITY	2%			
ARRAY LOSSES	4%			
BLADE FOULING	2%			
ELECTRICAL LOSSES	2%			
OTHER LOSSES	2%			
NET LOSSES	**12%**			
NET ENERGY / YEAR	**520,331**	1.72E+08 KWHRS / YR		

NPS

TABLE 2: GREAT PLAINS WIND FARM FIGURE OF MERIT

COST OF ENERGY

50 MEGAWATT WIND FARM: 330 ADVANCED TURBINES

GREAT PLAINS SITE #2

		SERI PRESCRIBED VALUES		
DISCOUNT RATE		6.10%		
FIXED CHARGE RATE	FCR	10.20%		
INITIAL CAPITAL COST	ICC		$42,055,404	$850/KW
ANNUAL O&M	AO&M		$1,790,623	1.0428 ¢/KWHR

LEVELIZED REPLACEMENT COSTS LRC

LRC =PVF*$(YR)*CRF

CAPITAL RECOVERY FACTOR - CRF

PRESENT VALUE FACTOR - PVF

		PVF	CRF
AILERONS: YR 8	$693,000	0.6227	0.0730
YAW DRIVES: YR 10	$825,000	0.558	0.0730
OTHER: YR 20	$1,000,000	0.306	0.0730
LRC	$87,445		

COE =(FCR*ICC + AO&M + LRC) / ANNUAL ENERGY

ANNUAL LEVELIZED COSTS	$6,080,274
ANNUAL ENERGY FOR FARM	171,709,230 KWHR/YR

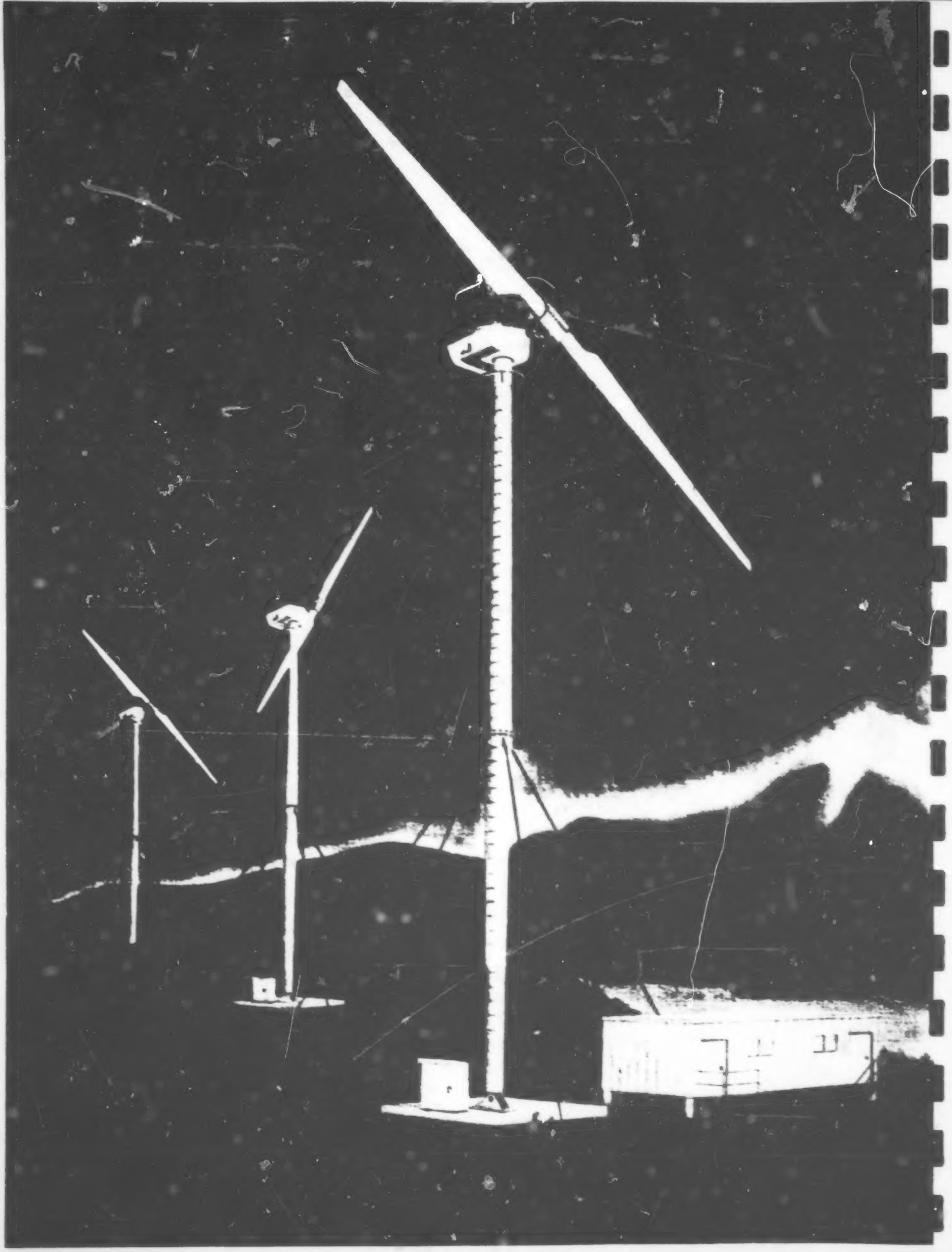
COE $0.0354 $/KWHR

NPS

TABLE 3 FIGURE OF MERIT COMPARISON

COMPARISON FOR GREAT PLAIN SITE: AVERAGE WIND SPEED IS 9.07 M/S AT 150 FT

TURBINE CHARACTERISITICS	NPS IMPROVED TURBINE	NORTH WIND 100	BONUS 120 with 150ft Tower
DIAMETER	70 FT (21.34 M)	58.9 FT (18 M)	64.3 FT (19.6 M)
ROTOR AREA M^2	357.7	254.4	301.7
RATED POWER	150 KW	100 KW	120 KW
PEAK POWER	167 KW	125KW	135KW
SALE PRICE	$98,911	$100,000	$121,000
TURBINE WEIGHT IN LBS	8250#	10,600#	19370#
FIGURES OF MERITS			
KWHR/YEAR	591,285	374,126	491,900
KWHR/M2	1653	1479	1629
$/M2	$277	$395	$401
KWHRS/POUND	72	35	25



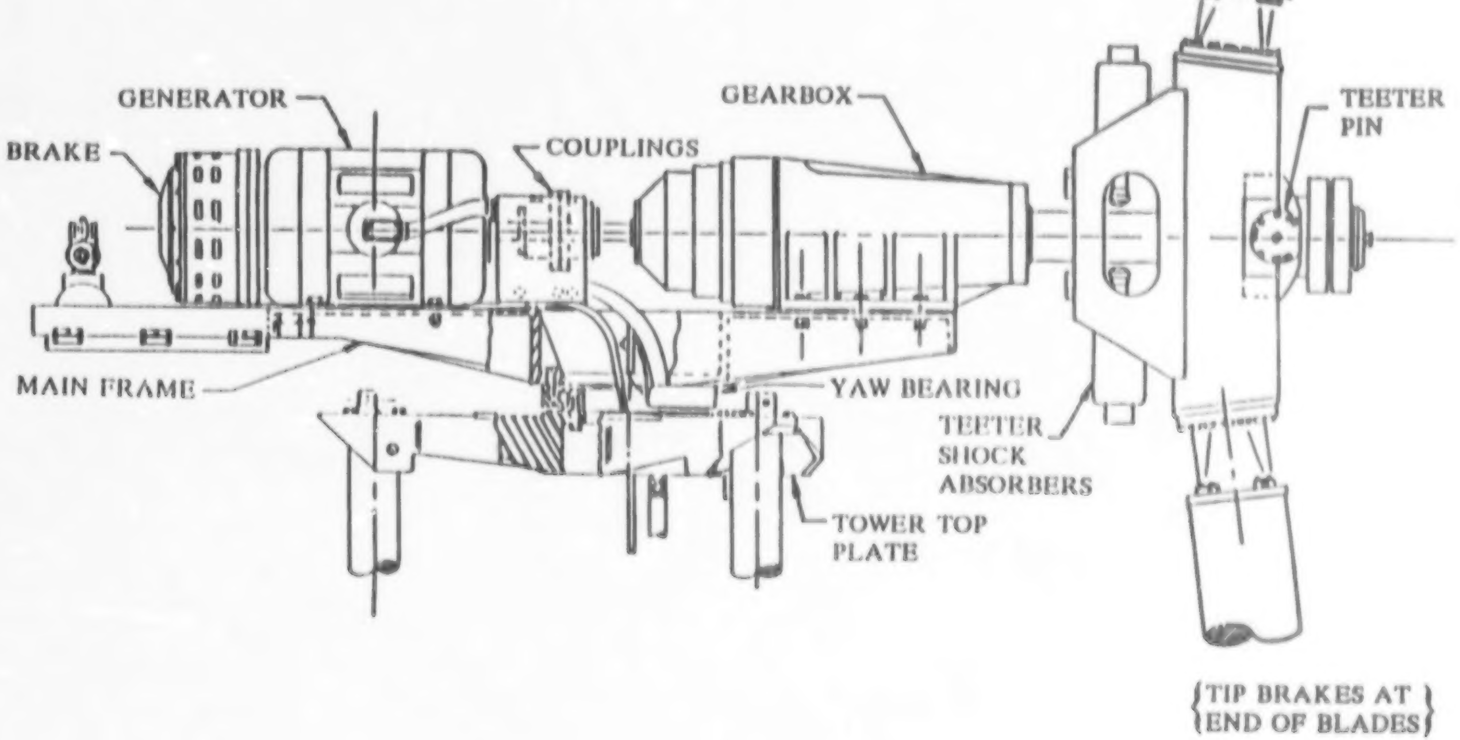
WC-86 ADVANCED WIND TURBINE DEVELOPMENT

John Rodgers
R. Lynette & Associates, Inc.
Redmond, Washington

Presented at:
Wind Power '91
Canadian Wind Energy Conference
Montreal, Quebec
November 5, 1991

SCOPE

- The starting point -- ESI-80
- Approach
- Results
- Plans for the future


BLADE
GENERATOR
GEARBOX
TEETER
PIN
BRAKE
COUPLINGS
MAIN FRAME
YAW BEARING
TEETER
SHOCK
ABSORBERS
TOWER TOP
PLATE
{TIP BRAKES AT
END OF BLADES}

ESI-80

THE ESI-80

- Light Weight (Low Cost)
- Two Blades (Lower Rotor Cost)
- Low Complexity
  - Fixed Pitch
  - Free Yaw
- Lower Loads via Teetered Hub
  But -- Rotor Performance Not Good

APPROACH

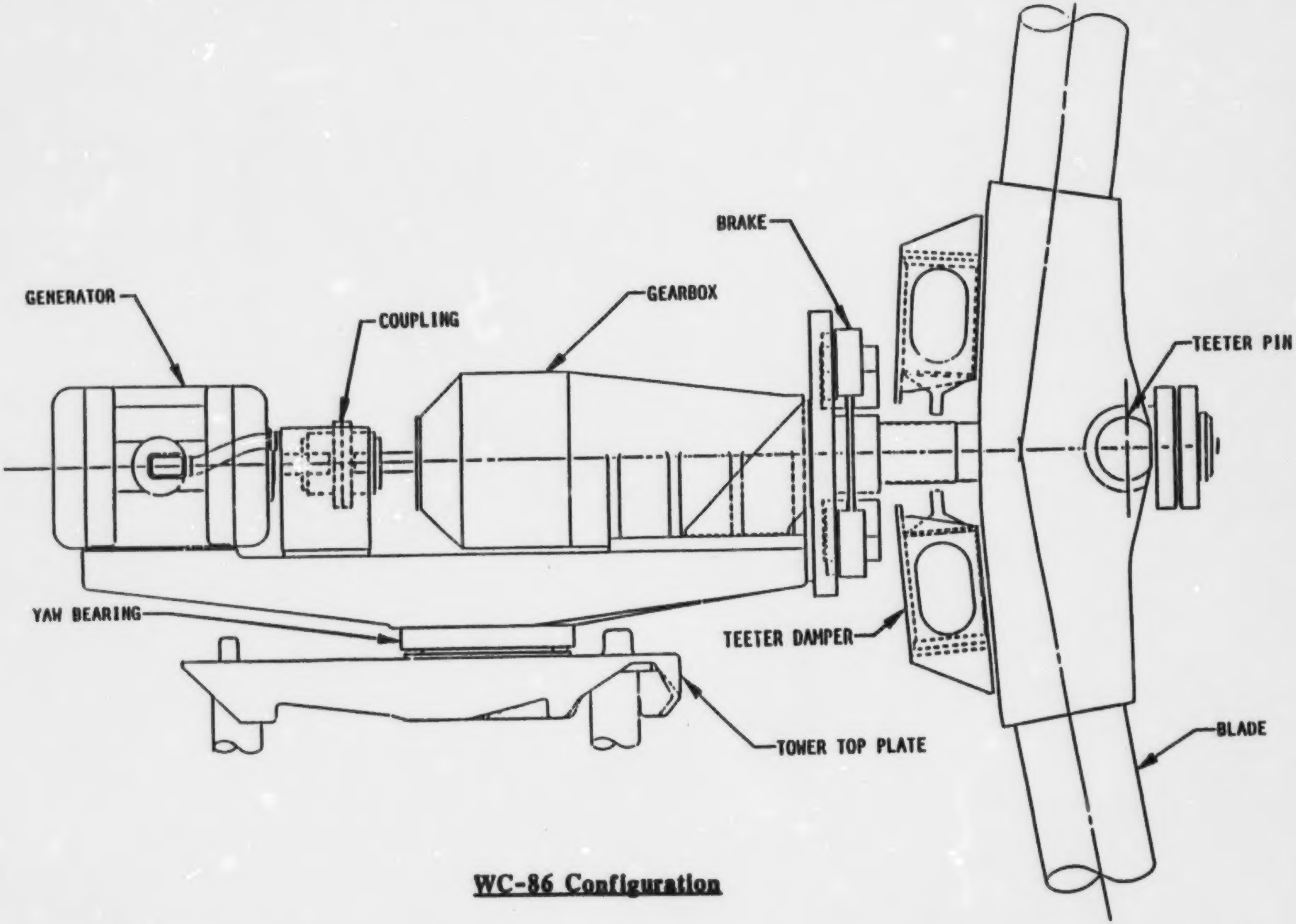
- Fix existing problems
- Use SERI airfoils to enhance performance
- Apply latest technology for control, braking, and power factor regulation
- Result:
  Light Weight + Simplicity + Lower O&M Costs
  + High performance = Low COE

ANALYSES PERFORMED

- Blade aerodynamic performance
- Rotor dynamics and loads
- Drive train dynamic modeling
- Finite element modeling
- Reliability/maintainability modeling
- Cost of energy calculations

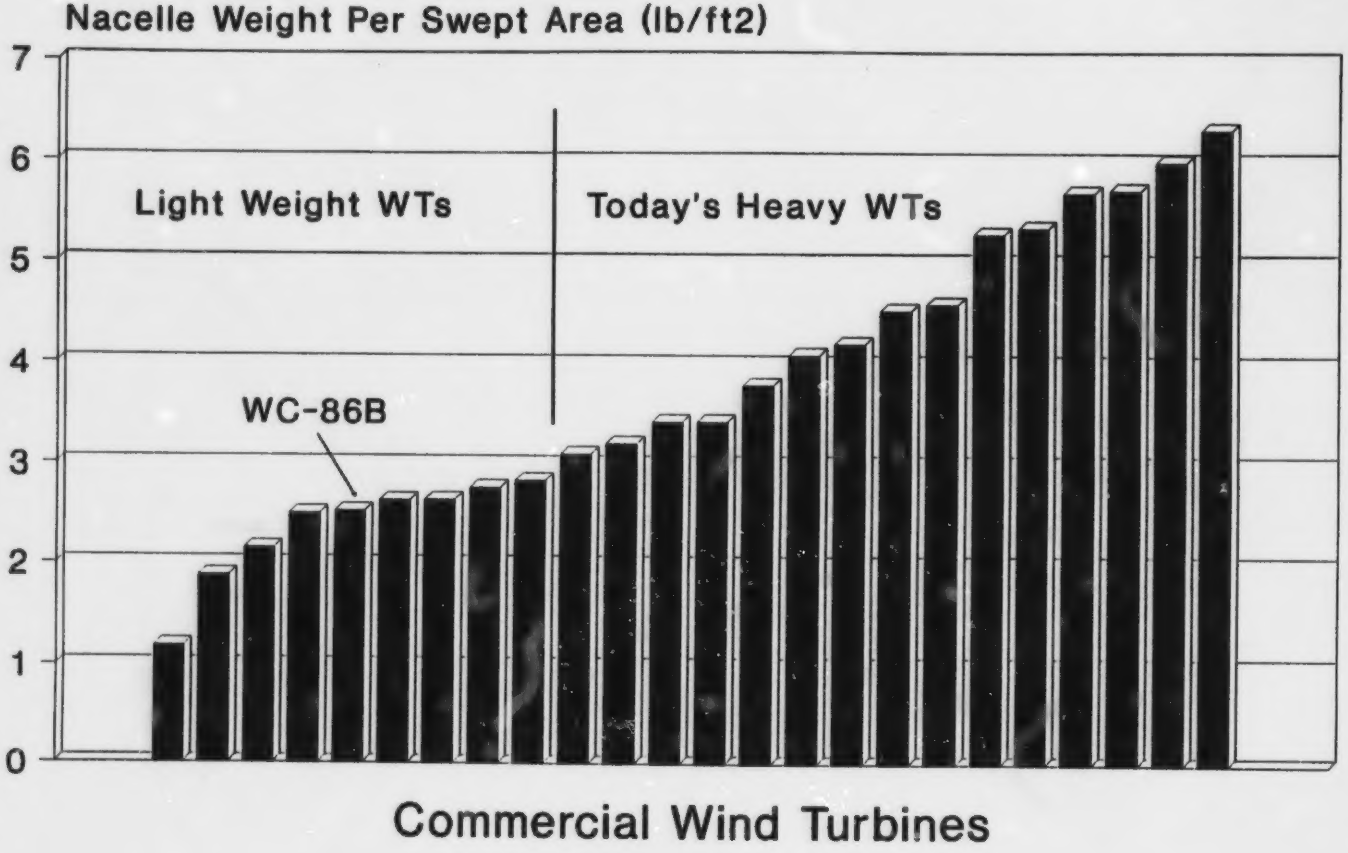
RESULTS

- All reliability problems addressed
- Rotor diameter increased to 86'
- Uses SERI advanced thick airfoils -- peak power limited
  - Dynamic braking -- for normal and emergency stops
  - Low speed brake added (emergency back-up)
- Soft-start and adaptive power factor control added
- Higher-rated gearbox and yaw bearing; enclosed generator

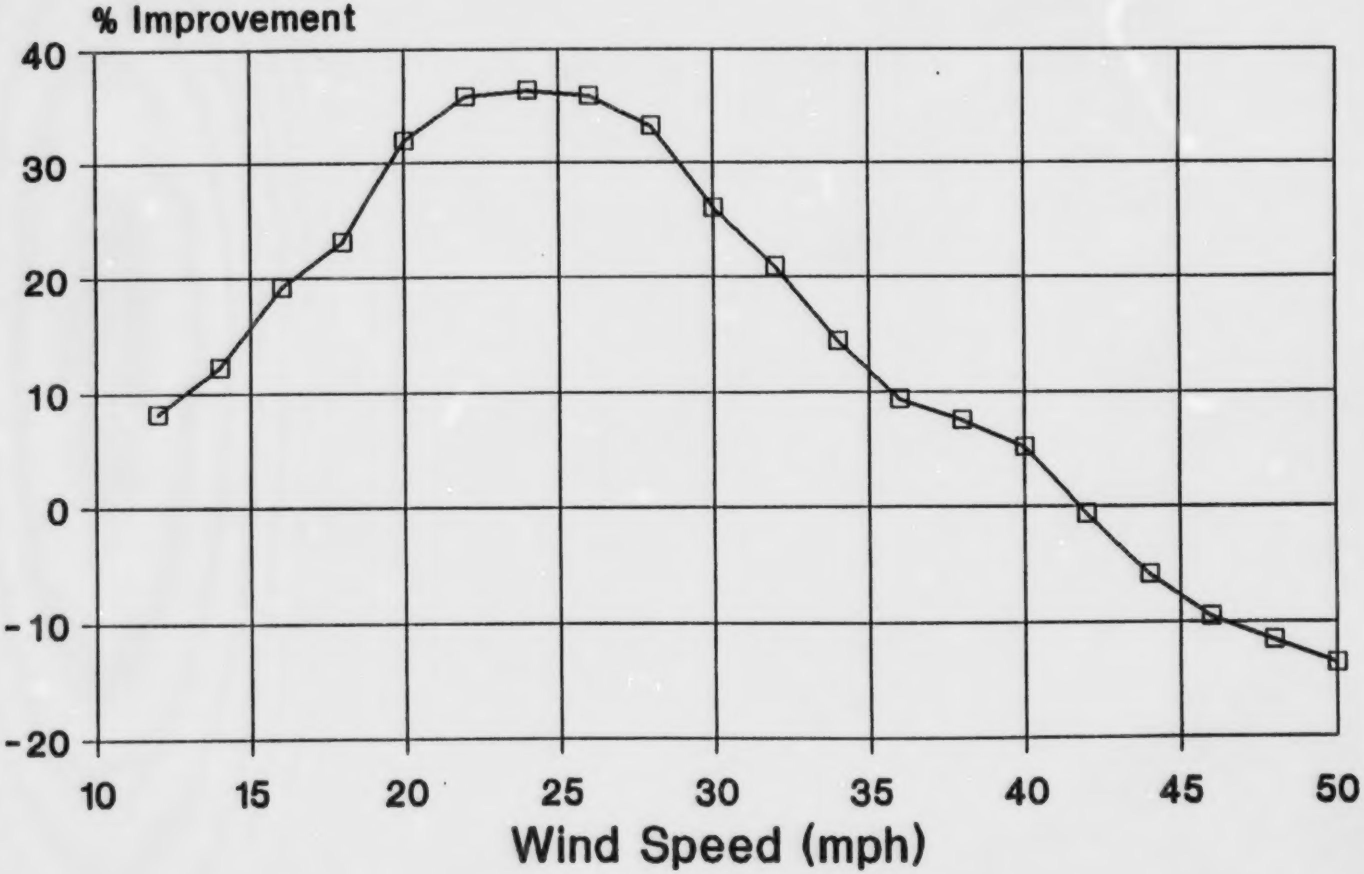

GENERATOR
COUPLING
GEARBOX
BRAKE
TEETER PIN
YAW BEARING
TEETER DAMPER
TOWER TOP PLATE
BLADE

WC-86 Configuration

WEIGHT VS. SWEPT AREA
(Less Tower)

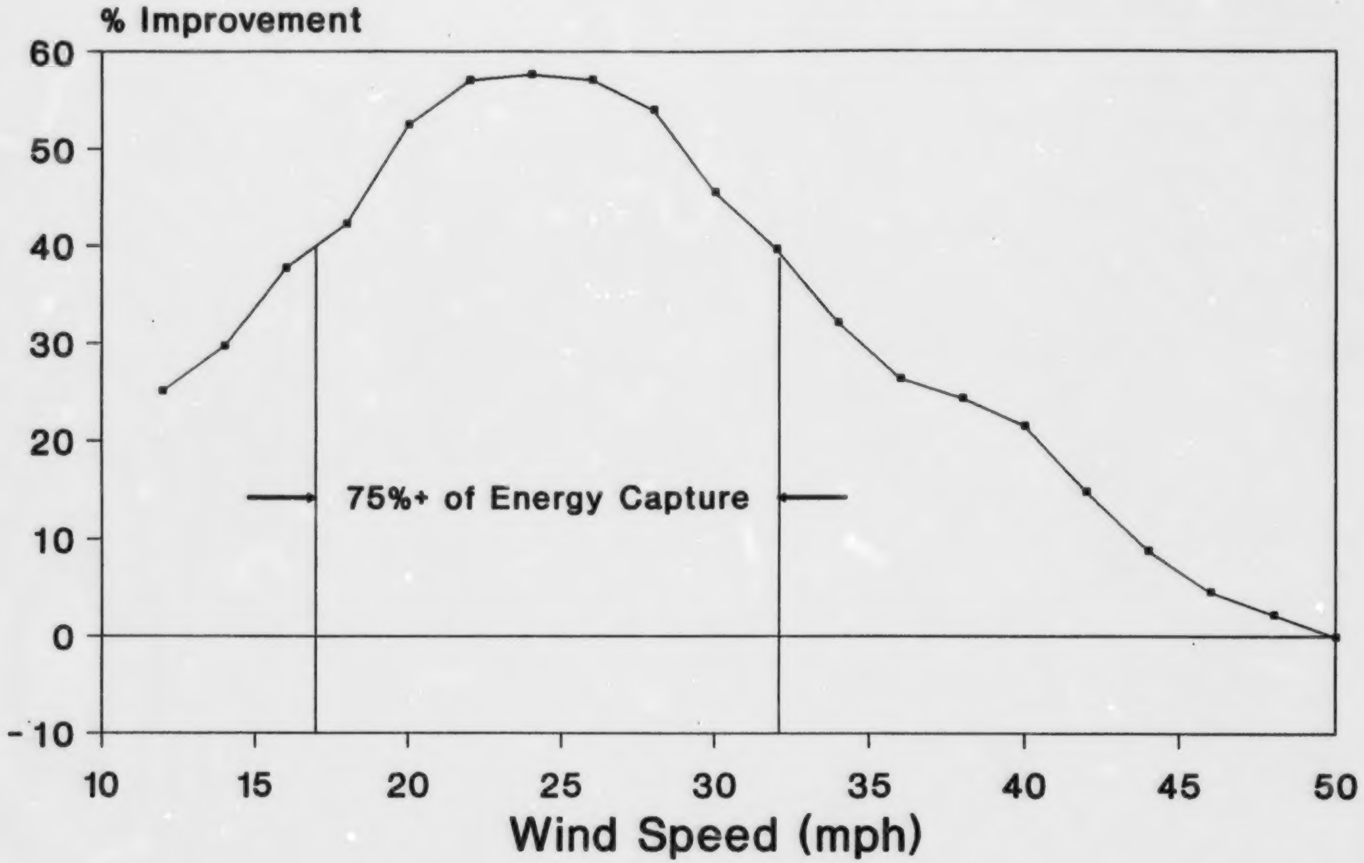


Improvement in Aero Efficiency
SERI Thick Blades over LS(1)

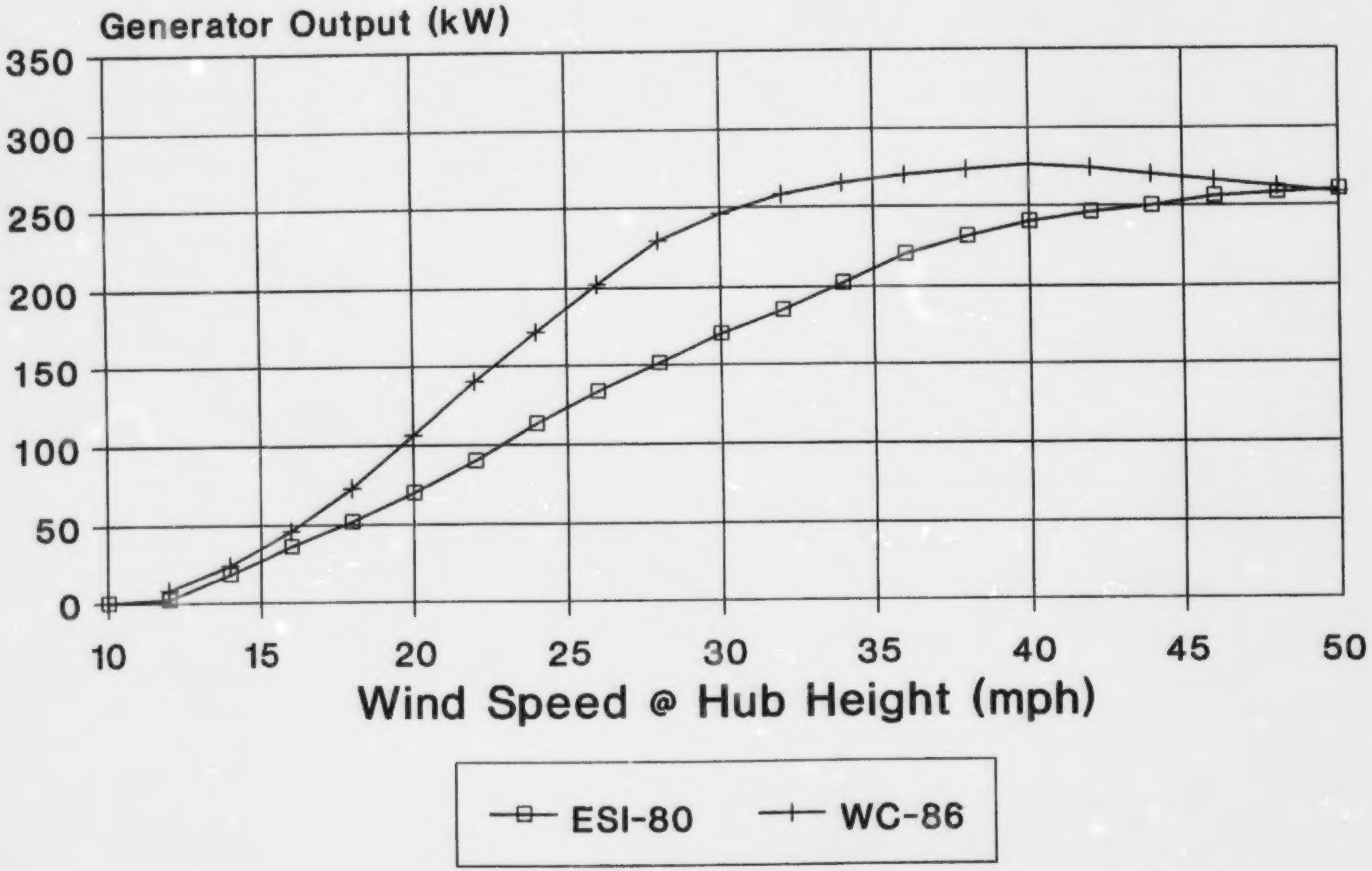


TOTAL IMPROVEMENT

(Aero + Area)



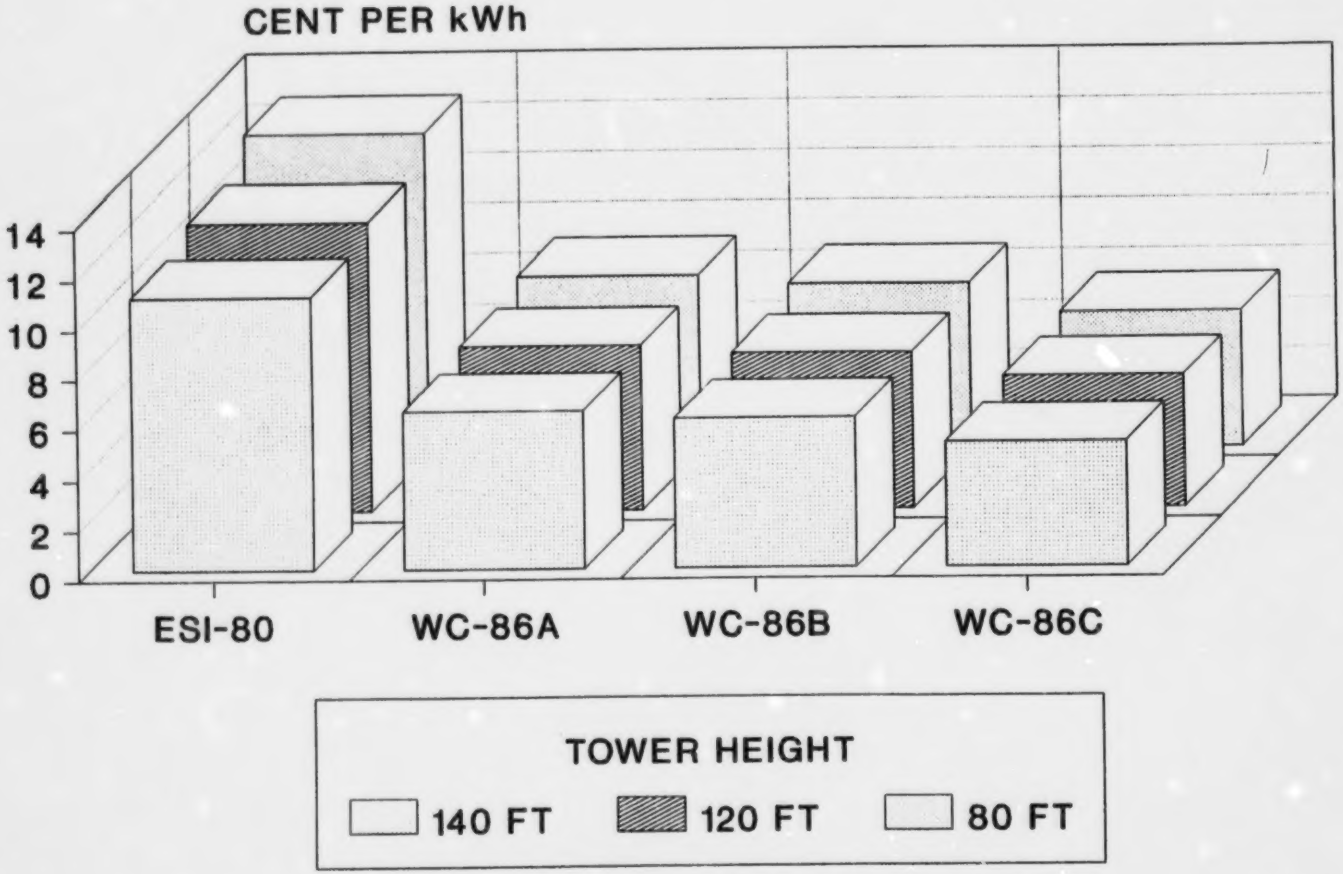
POWER CURVE COMPARISON
Sea Level



COMMERCIALIZATION PLANS

- *Advanced Wind Turbines, Inc.* formed to market WC-86B
- Test machine(s) in 1992
- Full production version test in early 1993
- Commercial sales in 1994

COST OF ENERGY
FOR 13 MPH SITE



Annual Energy Production

Average Annual Wind Speed @ Hub (mph)	Annual Energy Production (kWh)
14	440,580
15	522,875
16	607,415
17	693,040
18	777,400
19	857,170

Rayleigh distribution

ADVANTAGES

- Wood-Epoxy Blades (2 instead of 3)
  - Lower cost
  - Excellent Fatigue Properties
- Advanced SERI Airfoils -- High Performance
- Teetered Rotor -- Lower Capital Cost, Less Maintenance
- Stall Regulated -- Lower Capital Cost, Less Maintenance
- Passive Yaw -- Lower Capital Cost, Less Maintenance
- Dynamic Brake -- Lower Capital Cost, Less Maintenance

Result: 25-40% Lower Cost of Energy

The Status of the U.S. VAWT Program*

H. M. Dodd, D. E. Berg, T. D. Ashwill,
H. J. Sutherland and L. L. Schluter
Wind Energy Research Division
Sandia National Laboratories
Albuquerque, New Mexico

ABSTRACT

Vertical axis wind turbine (VAWT) technology in the United States started in the early 1970s directly from the original work in Canada. The close, and very productive relationships among laboratories, universities and industry have continued since that time. This paper briefly discusses the significant technical progress and rather dramatic programmatic changes that have occurred in the past 18 to 24 months on the U.S. side of the border.

INTRODUCTION

VAWT technology in the United States began at Sandia National Laboratories in the early 1970s, coming directly from the pioneering work of Templin and Rangi in Canada. The cooperative activities among laboratories, universities and the wind and utility industries in both countries have continued over the years, with the work described in Massé and Pastorel[1] simply being the latest example of that cooperation.

The keystone of the U.S. VAWT research and development program for the past four years has been the DOE/Sandia 34-meter VAWT Test Bed, last reported to a Canadian audience two years ago.[2] An excellent summary[3] of work conducted through early 1990 is available, and individual papers have also been presented at U.S. conferences during the intervening time. This paper highlights those results and presents progress not previously reported. Some results helped validate analytical tools, while others yielded surprises that are now providing new research directions.

The success of the VAWT research and development program led to a decision to pursue technology transfer opportunities with U.S. industry. Beginning with a public announcement

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*This work is supported by the U.S. Department of Energy at Sandia National Laboratories under contract DE-AC04-76DP00789.

and an open workshop held in May of 1990, Sandia began a new initiative to transfer the advanced technology demonstrated on the Test Bed to private industry and to assist, where needed, in developing a next generation of commercial VAWTs. An integral part of that effort was the VAWT Point Design,[4] and this paper presents a brief synopsis of that work as well as the ongoing cooperative activities with the U.S. industrial leader/partner.

STATUS OF THE VAWT TEST BED

Since its dedication in May 1988, the DOE/Sandia VAWT Test Bed has provided vital information concerning the improvements possible for the next generation of VAWTs. The last report to this conference was in 1989,[2] and included preliminary performance data. Since that time numerous papers have been published[3] and considerable progress has been documented. A brief summary of the Test Bed characteristics includes: a diameter of 34 meters, a height-to-diameter ratio of 1.25, power rating of 500 kWe at 37.5 rpm in a 12.5 m/s wind, variable speed operation (6-40 rpm) with most testing conducted from 28 to 38 rpm, step tapered extruded aluminum blades incorporating natural laminar flow (NLF) airfoils, a versatile programmable controller, and extensive instrumentation coupled with a state-of-the-art data acquisition and analysis system. The following sections describe recent significant findings in various areas of research; some results are specific to VAWT technology while others have impacted wind turbine research and development in general.

Aerodynamic Results/Issues. The Test Bed is the first wind turbine designed to utilize the VAWT-specific SAND 0018/50 airfoil, one of a family of symmetric, natural laminar flow (NLF) airfoil sections developed by Sandia researchers and Dr. Gerald Gregorek of The Ohio State University to achieve Sandia-specified performance characteristics.[5-8] These airfoils are tailored for use on a VAWT blade near the turbine equator. A major concern regarding the use of laminar flow airfoils on wind turbines is the degradation of performance that occurs due to roughening of the blade surfaces by dust, rain, and/or the residue from insect impacts. This concern was addressed in the design of the SAND airfoils, and we concluded that the performance of the SAND airfoils, even when roughened, would be superior to the performance of NACA 00XX-type airfoils similarly roughened.[7,8]

The portions of a VAWT blade near the tower operate in a much different environment than that experienced by the equatorial portion, and the NACA 00XX airfoils are far better suited for that environment than are the SAND airfoils.

The Test Bed blade incorporates both airfoil sections: the SAND 0018/50 airfoil near the equator and the NACA 0021 airfoil near the tower. A tapered blade with a smaller chord at the equator and a larger chord at the blade roots reduces blade material stresses while maintaining high rotor energy capture. The taper also maintains a relatively constant Reynolds number over much of the equatorial section of the blade, allowing the SAND 0018/50 airfoil to operate near its design point.

The blade material is extruded aluminum, chosen both because we have had considerable experience with it and because we anticipated the resultant blades would be less expensive than if they were produced with some other fabrication method. The use of extrusions forced us to adopt the step-tapered blade configuration illustrated in Figure 1. The blade chords were too large for single-extrusion airfoils; two extrusions were required for each of the SAND 0018/50 airfoil sections, and three extrusions were required for the 1.22-m (48-in) chord NACA 0021 sections. The extrusions for each airfoil were bolted together in the spanwise direction.

The predicted performance of the Test Bed is compared with data measured in January 1990 in Figures 2 and 3. The predictions were made with SLICEIT, a conservation-of-momentum based, double-multiple streamtube (DMST) code based on Paraschivoiu's CARDAA code.[9] The code incorporates the Gormont dynamic stall model,[10] as modified by Massé,[11] and accounts for local Reynolds number effects. The Massé correction is not used for that portion of the blade comprised of NLF airfoil sections. The agreement between measurement and prediction at moderate to high wind speeds is very good. The power regulation in the high-wind regime is particularly worthy of notice. It is due to the stall characteristics of the SAND 0018/50 airfoil section, and this regulation was one of the key objectives of the Test Bed blade design effort.

The agreement at low wind speeds is not as good. We feel that this discrepancy is at least partly due to the external blade-to-blade joint design shown in Figure 4. As can be seen in this drawing, these joints are not aerodynamically smooth; exposed bolt heads, blunt leading surfaces, and sharp corners all contribute to increased drag and decreased lift from this area of the blade. These effects were not modelled in the performance calculations, but we would expect them to result in decreased turbine performance, especially at low wind speeds.

In order to improve the turbine performance, we installed small aerodynamic fairings on these blade-to-blade joints, using a lightweight epoxy material with embedded fiberglass tape to cover the bolt heads and eliminate some of the sharp corners. The fairings were hand shaped and coated with enamel paint to give them a hard, fairly smooth finish. Measurements of the rotor aerodynamic performance with the fairings installed are summarized in Figures 5 and 6 for 28 and 34 rpm, respectively. The predicted performance curves in these figures are identical to those in Figures 2 and 3. Careful examination reveals that, although the differences are small, the fairings did appear to provide a small improvement in performance in low wind speeds and a small degradation in performance at high wind speeds. We feel the performance could be further enhanced with the installation of somewhat larger teardrop-shaped fairings. But the cost would be significant, so we plan to retain our present fairings for the near-term future.

In May 1990, we ran the first extensive tests during a season when significant quantities of insects were present. After a few days of operation, we noticed that there was a large number of turbine stops due to turbine overspeed in high-wind conditions at 34 rpm. This was an unexpected situation for those operating conditions. Investigation showed the overspeed condition was caused by power production that exceeded the generator capacity (500 kWe). The turbine was producing about 540 kWe at 17 mps, and it normally produced only 480 kWe at that wind speed. A review of the data obtained at 28 rpm that same month revealed the results shown in Figure 7; once again the data obtained in May showed a significant increase in power at high wind speeds, as compared to data obtained during the winter months. An inspection of the turbine blades revealed some accumulation of bug debris, but intuition and experience argued that should cause a decrease in maximum power output, not a 15% increase!

Since the biggest difference in performance came in the power regulation portion of the power curve, we decided to collect more performance data at 18 rpm where the regulation occurs at lower and more prevalent wind speeds and to monitor any change in performance due to natural rain washing. These data, presented in Figure 8, are confined to the power regulation portion of the performance curve, and the data curves are rather rough because the amount of data acquired for each case was quite small. The data marked *7/19/90* are base-line performance data with dirty blades (bug debris and dirt accumulation from several weeks of running in the summer). The *7/24/90* data, at a slightly lower maximum power level, were obtained immediately after a heavy rain fell on the parked turbine. The *8/16/90* data were taken immediately after the turbine was run for nearly an hour during a heavy rain shower. These data show a significant decrease in the maximum power level (approximately 15% below the dirty blade level).

As seen in Figure 9, 28 rpm performance data with the rain-washed blades, obtained on 8/22/90, compare very well with performance data obtained in February, when we know the blades were free of any dirt and/or bug debris.

This evidence all indicates that the accumulation of bug debris and dirt on the Test Bed blades caused a 15% increase in maximum power output at 18 rpm during the summer of 1990. We also observed increases in maximum power output at 28 and 34 rpm, due to the dirty blades, but we do not have enough data to determine the magnitude of maximum power increase at those rotational speeds.

While this increase in maximum power output due to blade roughness is in marked contrast to the sharp decrease normally observed, it is still a problem. Any sensitivity of blade performance to roughness is undesirable, for while a decrease in power implies lost revenue, an increase in power may well lead to premature drivetrain component failure.

We speculate that the presence of the roughness on the Test Bed NLF blade sections delays blade stall and separation of the boundary layer, leading to higher maximum lift and increased maximum power. We have initiated a research effort with Dr. Gerald Gregorek at The Ohio State University to further investigate the effects of naturally occurring roughness on the performance of the SAND 0018/50 airfoil. In contrast, other experimental results to date utilizing NREL(SERI)-developed bug-roughness simulations have all yielded increased drag and decreased maximum lift. But this would correspond to decreased Test Bed maximum power output, rather than to the observed increased output.

Apparently the effect of roughness on the Test Bed blades is heavily dependent on the detailed characteristics of that roughness, and we will have to determine those characteristics before we can fully understand the roughness effects. This is probably true of HAWT blades as well, but we do not have enough data to be sure. Determining the characteristics of blade roughness is difficult, as normal contact-type methods are tedious and not very accurate, and the available non-contact systems are not well suited for this application. Obviously, those characteristics will vary from site to site and from season to season, so we need a measurement technique that is fairly speedy and easy to use. We are currently evaluating the feasibility of developing a non-contact surface mapping system specifically for this application.

Future plans call for the modification of the root sections of the current blades with the installation of vortex generators (VGs). Analytical studies, based on previous tests of vortex generators on VAWTs,[12] indicate that appropriately placed VGs could yield performance improvements of up to 5% at moderate wind speed sites.

Structural Dynamics. The Test Bed project provided an opportunity to exercise our analytical tools in a complete VAWT design process. The primary structural tools, our NASTRAN-based codes, FEVD and FFEVD, perform natural frequency analyses and steady-wind, forced-response analyses, respectively. The validation of these codes and the finite element model is an ongoing effort as operational data become available.

As reported earlier,[2,13] comparisons between measured and analytical data have been completed in several areas. For example, measured deterministic stresses, both gravitational and centrifugal (at several rotation rates), compare closely to analytical results. In addition, stationary natural frequencies were measured with a modal test and compared to FEVD predictions. The measured frequencies of the first ten modes agree with the predictions to within 2% except for a blade-edgewise mode, which differs by only 5%. Measured rotating natural frequencies also compare closely to FEVD results.

Since 1989 many hours of data have been collected at 28, 34, and 38 rpm in winds to 20 m/s. These data have been binsed and compared to predicted operating stresses.[14] The steady wind predictions (determined by FFEVD) are reasonably close to measured values in winds of up to 11 m/s, but diverge from measured values in higher winds. Figure 10 shows this for the case of a lower root, flatwise gauge. Turbulent wind predictions were determined with TRES4, a recently developed code,[15] and show good agreement to measured values at most wind speeds and rotation rates (Fig. 11). However, more work is required to determine aeroelastic damping values and aerodynamic loads in dynamic stall operation.

Upcoming tests include a rotating transient test, which will induce a known force into one blade by releasing a pretensioned cable. It will be performed at several rotation rates and in very low winds to eliminate aerodynamic loads. The measured strain-time histories will be studied to confirm predictions of aeroelastic damping.[16] These results will also be compared to calculations from VAWT-SDS, a time domain code that incorporates turbulent winds and includes both rotating effects and controls/structure interactions. Plans also include the addition to this code of nonlinear aeroelastic effects.

Fatigue. In addition to Sandia's long-term involvement with VAWT technology, several generic research areas have received considerable attention for the past several years. The largest of these is fatigue, and Sandia has been developing an analytical framework for determining the service lifetime of turbine components.[17] The Test Bed has played a key role in providing measured data for design code validation. This design code, called LIFE2, is a fatigue/fracture analysis code that is specialized to the analysis of wind turbine components. The numerical formulation of the code uses a series of cycle count matrices to describe the cyclic stress states imposed upon the turbine. However, many structural analysis techniques yield frequency-domain stress spectra, and a large body of experimental loads (stress) data is reported in the frequency domain. To permit the analysis of this class of data, a Fourier analysis module was added recently to the code. The module transforms the frequency spectrum to an equivalent time series suitable for rainflow counting by other modules in the code. The addition of the module is a major milestone in the development of the code and significantly increases its capabilities.

The Fourier analysis computation module and its associated analysis techniques are described in a paper[18] to be published soon. The application of the module to a wind turbine component is illustrated by the examination of stress spectra from the Test Bed. A typical result is shown in Figure 12. In this figure, the cycle counts from a frequency domain analysis are compared to rain-flow counted cycles from time series data and to the narrow band Gaussian model that has been proposed by Veers.[19] It should be noted that the Gaussian model presented has a different RMS value (based on a large set of time series) than the two time series presented. As illustrated by this figure, the cycle counts from the frequency domain analysis closely follow the cycle counts from the time series data and from the Gaussian model in the main body of the distribution. In the high-stress tail of the distribution of cycle counts, the ability of the analysis technique to generate relatively long time series permits the tail to be defined with a stable, finite, relatively smooth, and monotonically decreasing distribution of the cycle counts. Although the "correct" distribution of cycle-counts in the high-stress tail is still under study, the synthesis of time series data from frequency domain data is an effective technique for the determination of stress cycles imposed on a wind turbine component.

Controls. The Sandia 34-meter Test Bed is equipped with a variable-speed/constant frequency (VSCF) generator system, which is controlled by an Allen-Bradley programmable controller. A personal computer is used to communicate with the controller and to display the current control parameters. This system offers a unique capability to evaluate various control algorithms. For example, the controller can be programmed to operate the system as a fixed-speed, a two-speed, or a variable-speed wind turbine. Tests can be performed to quantify the advantages and disadvantages of each mode of operation. Control algorithms implemented to date include operator-selected, fixed-speed operation; variable-speed operation; full automatic operation; and regenerative braking. All of these control modes include algorithms for the avoidance of structural modes within the operating range of the turbine. The next generation of control algorithms will include artificial intelligence, adaptive control, and "fuzzy logic" concepts. The flexibility of the Test Bed will also allow us to implement these algorithms so that the enhancements in energy production and fatigue life can be determined.

The Test Bed also provides the capability to verify a design code called ASYM.[20] The code permits a designer to examine the effects of various control strategies on the production of energy and the consumption of fatigue life for a wind turbine. ASYM uses a random wind as input to a wind turbine model. The model can be set up to use various control algorithms, as well as various material fatigue and output power characteristics. ASYM is used to select optimal values for start and stop control decisions based on wind speed, power production, and/or fatigue damage rate. With the capability to operate in different control modes and with its extensive instrumentation, the Test Bed gives us the capability to verify the analytical models used in ASYM.

VAWTs AND TECHNOLOGY TRANSFER

As a result of the technical successes of the Test Bed program discussed above, a decision was made in FY90 to initiate a major effort to identify an industry partner and, through cooperative agreements, translate the demonstrated improvements into a commercial product. This intent by Sandia was publicly advertised, and more than a hundred direct contacts with industry were made. The technology transfer strategy included conducting fairly detailed performance and structural designs on a "pre-commercial" version of the Test Bed -- the Point Design[4] -- and then presenting the results and proposed plans to interested parties at an open workshop. The remainder of this section first discusses details of the Point Design, then presents some aspects of how cooperative agreements are implemented in the U.S.A. and finally describes the nature of the new commercialization activities.

VAWT Point Design. In developing a point design it was appropriate to use the best features of the Test Bed to develop a design that eliminates the research items, reduces component weights and lowers costs. Although the size of the rotor was not optimized, a 34 meter diameter turbine was chosen based on our experience with the Test Bed, its known costs, and the quality of comparisons between measured and analytical data. The design philosophy of a point design is much different than that of a research machine. The design goals of the Test Bed were:

1. To provide a conservative design. This was the first time our full suite of design tools was used for a design process, and their accuracy was not completely known.

2. To incorporate a modular design. This feature allows change-outs of components, including individual blade sections.

3. To realize that the turbine is a one-of-a-kind construction. Detailed optimization to manufacturing methods and mass production techniques (as would be done for a commercial machine) was not emphasized.

4. To allow for single-blade operation without counterbalance. This meant larger bearings and bearing housings were required to withstand the inherent eccentric loading.

On the other hand, our point design goals were:

1. To minimize the changes from the existing, tested configuration, and maintain the operating stress levels. We recognize that this is just a single design, which is useful in economic studies, but is probably not the optimum design.

2. To maintain a maximum power output level of between 500 and 600 kW and incorporate power regulation by retaining the laminar flow blade sections.

3. To reduce oversized items.

4. To minimize the number of blade joints.

5. To reduce costs by using off-the-shelf items wherever possible.

6. To keep the tower and cables stiff enough to place the tower in-plane 3P resonance above the operating speed.

Figure 13 shows a drawing of the 34-m Point Design and the features that distinguish it from the Test Bed. The major changes from the Test Bed are the following:

1. Tower: The tower is smaller (2.1-m diameter instead of 3.0-m), which was possible because the turbine was assumed to have two blades.

2. Blades: A laminar flow blade with a 0.91-m (36-inch) chord and SAND 0018/50 profile for the equatorial section maintains the power regulation. The

root sections remain a 1.22-m (48-inch) chord, NACA 0021 profile. This configuration eliminates the 1.07-m (42-inch) transition sections on the Test Bed and two major blade-to-blade joints on each blade. One additional minor blade-to-blade joint in the 0.91-m (36-inch) chord equatorial section on each blade is necessary due to limits on the lengths of extrusion (24 m). Possible extensions to this extrusion length or slight reductions in the overall turbine size would eliminate this joint.

3. Generator: Operation occurs at 36 rpm in a single-speed mode. Two-speed operation is possible, but the variable-speed option is eliminated because of its current high cost.

4. Others: Due to the elimination of the requirement for single blade operation, the bearings, bearing housings, and bearing shafts are significantly lighter. The use of off-the-shelf brakes will lower costs substantially compared to the Test Bed brakes, which were designed and built in-house.

Aerodynamic Characteristics. Figure 14 shows the predicted performance for both the Point Design and the Test Bed at 36 rpm. The Point Design shows a power curve very similar to that of the Test Bed. It exhibits power regulation and actually has higher power levels at high winds due to the longer 1.22-m (48-inch) NACA section. Peak shaft power is 585 kW at 17 m/s.

Structural Characteristics. Structurally, the goal was to keep the operational stresses of the Point Design to levels no higher than those of the Test Bed and maintain the tower in-plane mode crossing of the 3P harmonic above the operating speed.

Several iterations between the aerodynamic code, CARDAA, and the structural codes, FFEVD and FEVD, indicate that we can place the mode slightly above 40 rpm and still retain a rotor that achieves a maximum power of 585 kW at 36 rpm.

Predicted operating stresses at 36 rpm and 11.2 m/s (25 mph) for both the Point Design and the Test Bed were examined, and, as expected, the stress distribution along the blades is very similar for both cases.

In conclusion, the Point Design differs minimally from the Test Bed which has proven performance and thus low technological risk. Initial hardware cost for the Point Design was estimated at $800,000, but with a more detailed design and quantity production, this cost should be more than halved. The Point Design is a first step towards a Test Bed-based commercial machine that would be competitive with conventional sources of power in the mid-1990s.

Cooperative Mechanisms Between National Labs and Industry. Recent growth in the federal wind program has focused on cooperative and/or cost-shared efforts involving the wind industry and the national labs; in fact, the two-year growth in funding from $8.6M in FY90 to $20.4M in FY92 has been almost exclusively earmarked for these areas. Since certain aspects of cooperative activities between national laboratories and private industry in the United States may be unfamiliar, this section briefly describes the general kinds of collaborative agreements that can be employed and indicates those chosen for our current technology transfer activity.

Several mechanisms have existed for years to encourage certain types of cooperation and/or cost sharing between the national labs and private industry. First, conventional, competitively bid proposals can require cost-sharing from the industry participant. In this case, contract awards are based on both technical merit of the proposal and the level of cost sharing proposed. The best example of this type is the series of Advanced Wind Turbine solicitations (a three-phase program) being directed by the National Renewable Energy Laboratory (NREL), formerly SERI. In this arrangement, the private company must provide a significant fraction of the total costs and may request assistance from the national labs as part of the activity. Another form of cooperation involves a no exchange of funds (NEF) agreement whereby an effort of mutual interest to industry and the DOE is undertaken, and the parties agree to fund their own efforts and share the results. Finally, industry can request support from a national lab by agreeing to fully pay for the work (which must be done on a non-interference basis by the laboratory). The advantage of this kind of agreement, called work for others (WFO), is that all results are the exclusive property of the funding party and can be kept proprietary.

Unfortunately, the above mechanisms have not always proven to be effective, particularly for the emerging wind industry, which has been severely undercapitalized and often lacking in technical staff. Late in 1989, the President signed into law a new mechanism, which promises to complement the above processes and encourage more effective technology transfer. The result of the law is a new Cooperative Research and Development Agreement (CRADA), which has several unique features. First, CRADAs are made directly between the industry partner(s) and the DOE laboratory, with the DOE providing only initial approval. No funding can flow from the government (through the laboratory) to industry, but money can flow from industry to the laboratory. But the laboratory can provide staff, hardware or protected property (e.g., patents and copyrights). Important aspects of CRADAs are that the industry partner can be given exclusive rights to produce a product, and that intellectual property can be held proprietary (i.e., exempt from the Freedom of Information Act) for up to five years. Equal opportunity to participate in a CRADA must be provided if the laboratory initiates the technology transfer effort; but industry is also allowed to initiate the process, and in this case no open solicitation is required.

The Industry Partner. As a result of a response to the publicly announced workshop mentioned above, FloWind Corporation of Pleasanton, California, was chosen as the industry partner for the advanced VAWT technology transfer process. Because a CRADA could not be formalized in the required timeframe, a combination of existing cooperative mechanisms was chosen for the initial set of tasks. First, a FloWind-funded effort was initiated under a WFO for Sandia to assist in an evaluation of a repair program for FloWind's existing fleet of over 500 VAWTs in California. This effort also includes the design, procurement and installation of data acquisition systems, including both stationary and rotating units. The installation of the stationary units was completed in mid-October, while the rotating, RF-based system was successfully demonstrated on the Test Bed in early October and will soon be moved to California.

At the same time the WFO was implemented, a FloWind/Sandia NEF was also created with the primary purpose of applying some of the improved components demonstrated on the Test Bed to a product improvement program. Specifically, the copyrighted analytical tools that have been validated by the Test Bed, as well as specific components such as the NLF airfoils, are being incorporated into an improved design based on the existing FloWind F-19 turbine.

The final element of this cooperative activity is a plan to optimize the entire Test Bed configuration into a commercial product. The Point Design discussed above is almost certainly not this optimum, but it will be used as the starting point for determination of what the most cost-effective VAWT for the mid-1990s and beyond should look like. This collaboration is just getting underway and will probably take the form of a CRADA.

SUMMARY/CONCLUSIONS

Since the 1989 CANWEA conference, significant technical progress has been demonstrated for VAWT technology in the United States; and the VAWT Test Bed has proven to be the cornerstone for that progress. Of even greater long-term significance, however, is the renewed role of FloWind Corporation in efforts to commercialize this progress. The collaborative efforts between Sandia and FloWind are characteristic of the new emphasis in the DOE Wind Program to combine the federal and private sectors in efforts to improve energy security, positively impact the environment and increase U.S. economic competitiveness in the energy sector worldwide.

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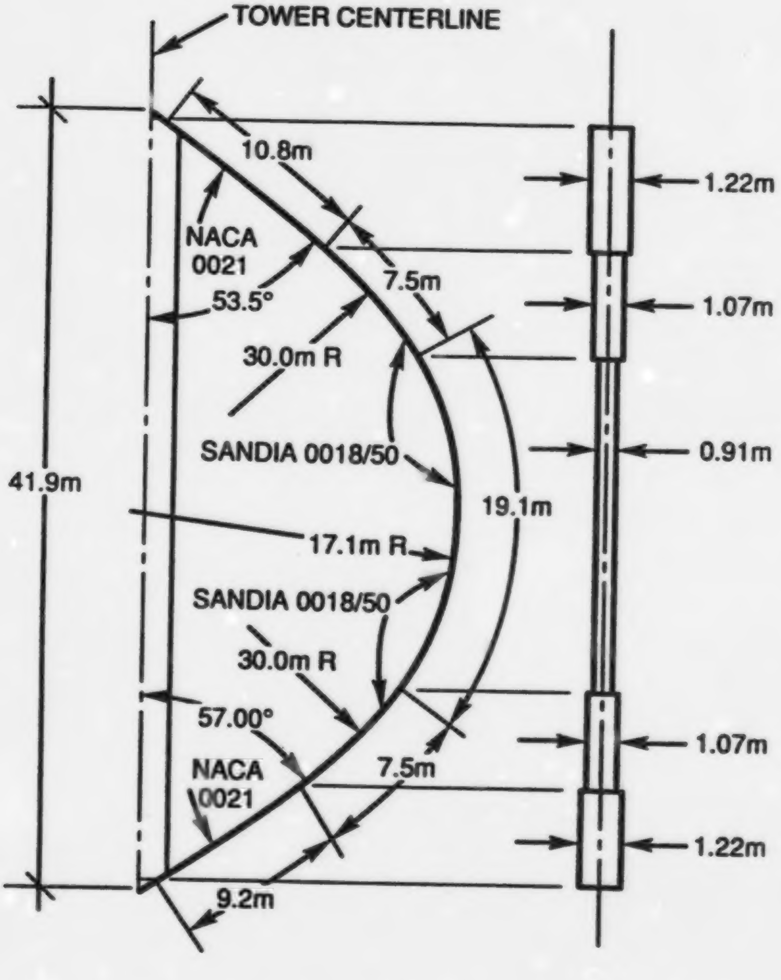

TOWER CENTERLINE
10.8m
1.22m
NACA
0021
7.5m
53.5°
1.07m
30.0m R
SANDIA 0018/50
0.91m
41.9m
19.1m
17.1m R
SANDIA 0018/50
30.0m R
57.00°
1.07m
NACA
0021
7.5m
1.22m
9.2m

Figure 1. Test Bed Blade Configuration

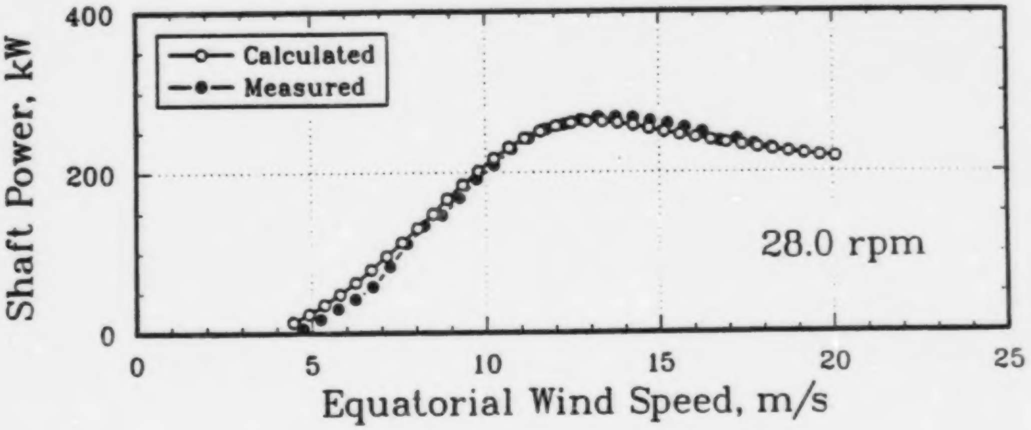


Figure 2. Test Bed Performance at 28 rpm

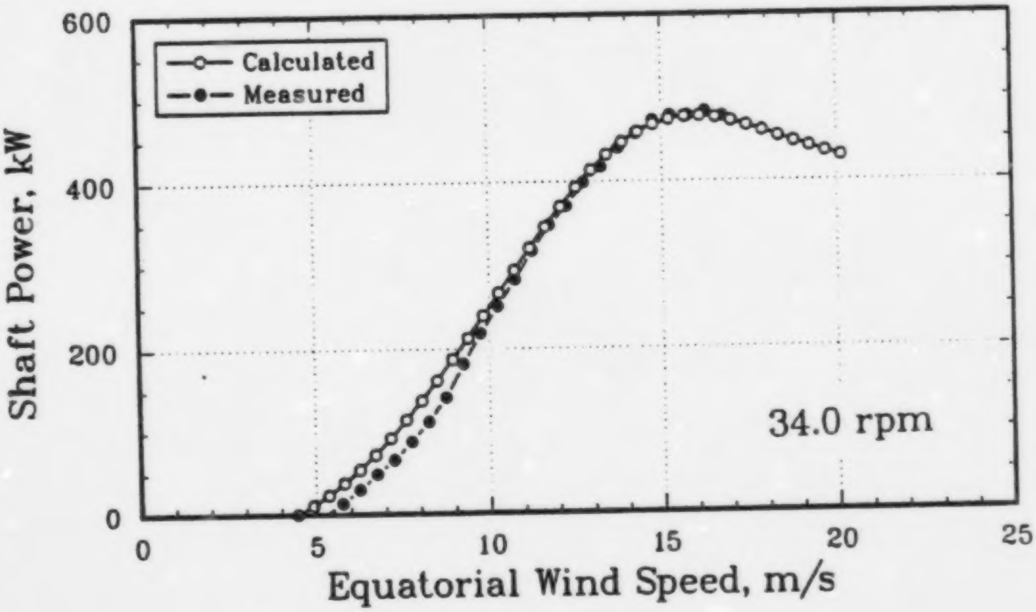


Figure 3. Test Bed Performance at 34 rpm

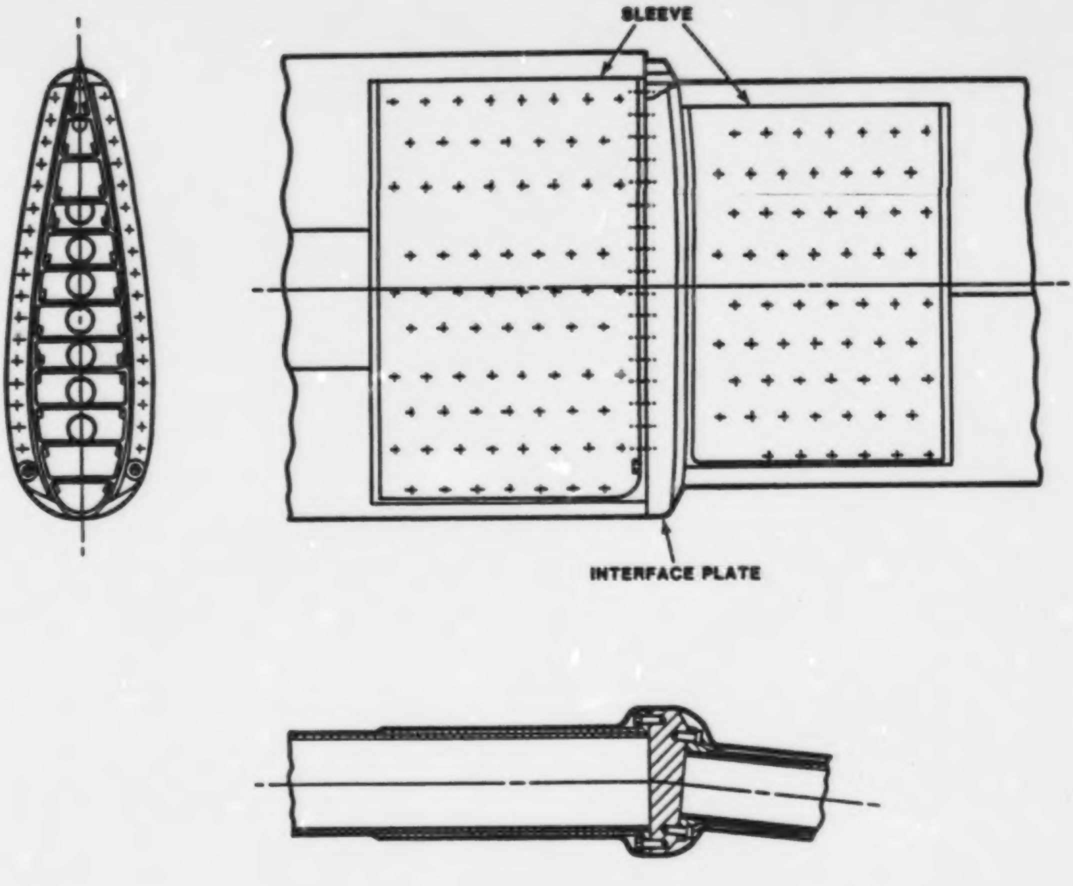

SLEEVE
INTERFACE PLATE

Figure 4. Blade-to-blade Joint Configuration

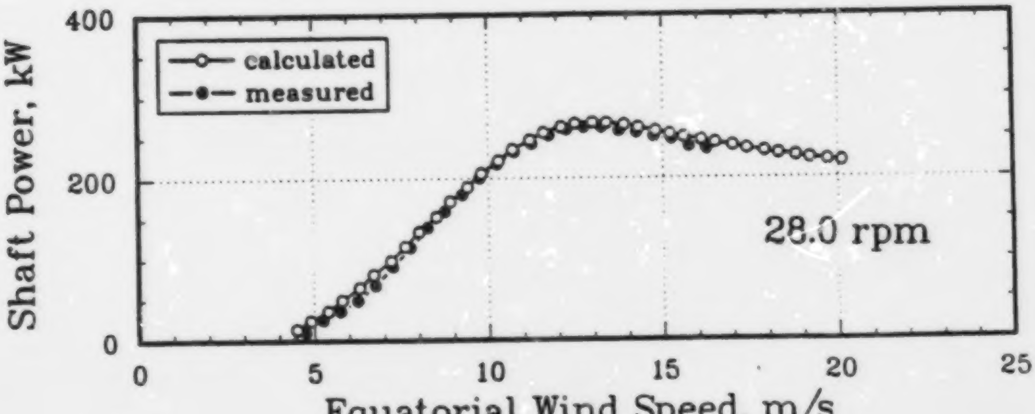


Figure 5. Test Bed Performance with Fairings at 28 rpm

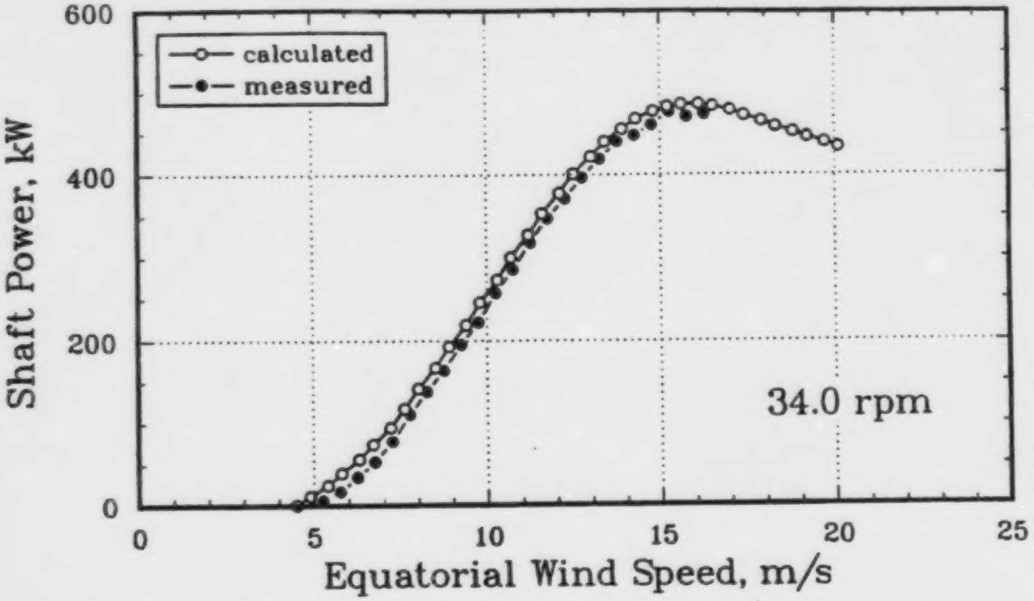


Figure 6. Test Bed Performance with Fairings at 34 rpm

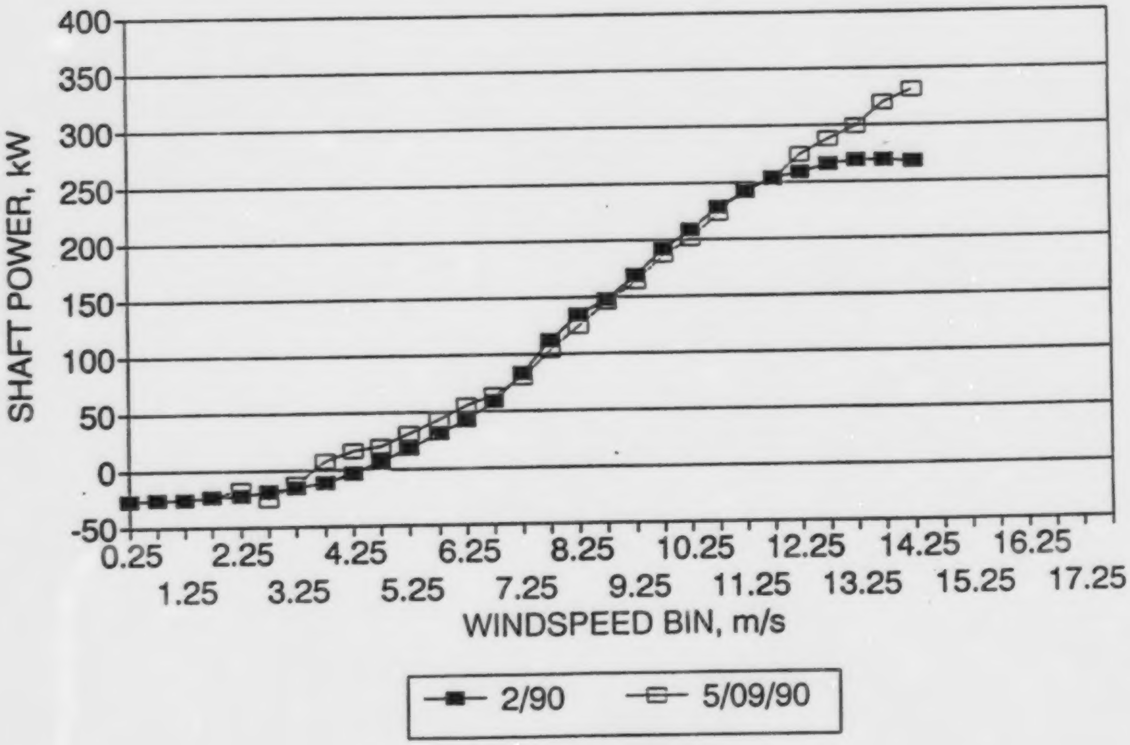


Figure 7. Turbine Performance at 28 rpm.

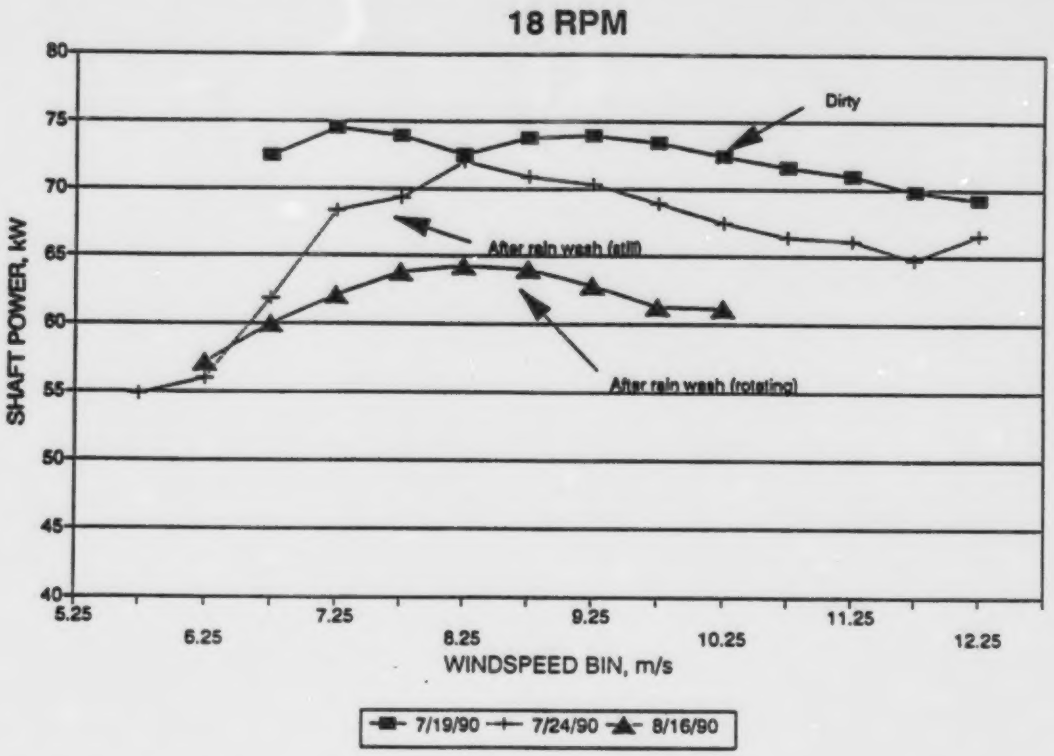


Figure 8. Effect of Rain Washing on Turbine Performance at 18 rpm.

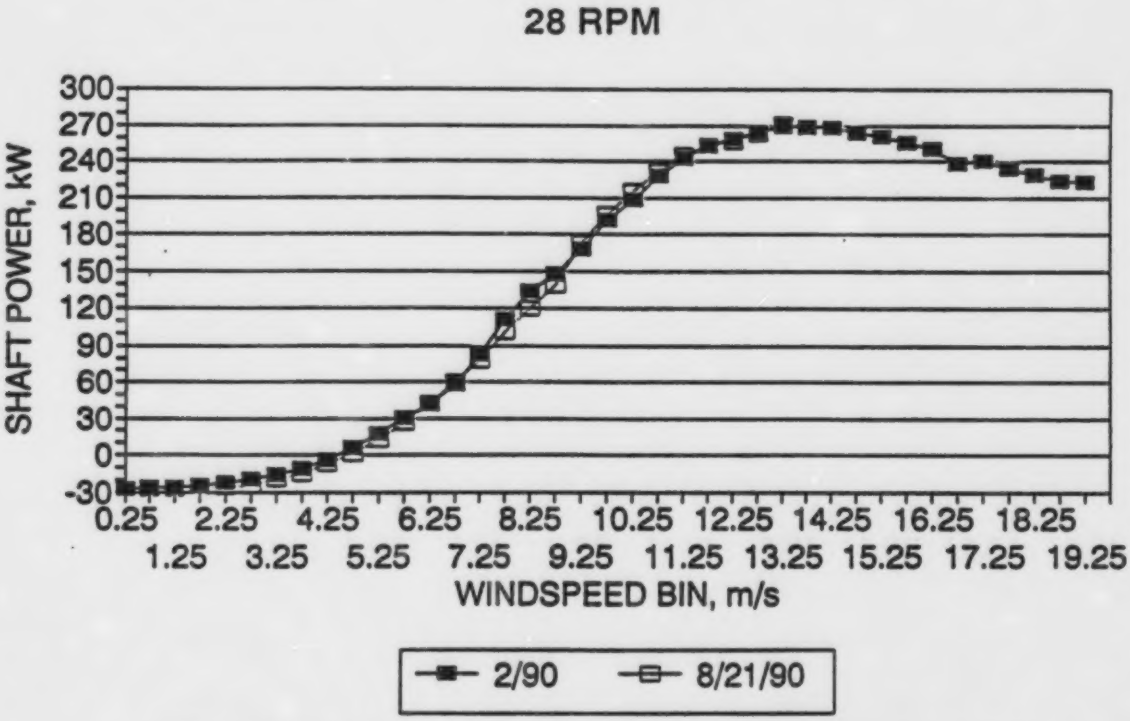


Figure 9. Turbine Performance with Clean and Rain-Washed Blades.

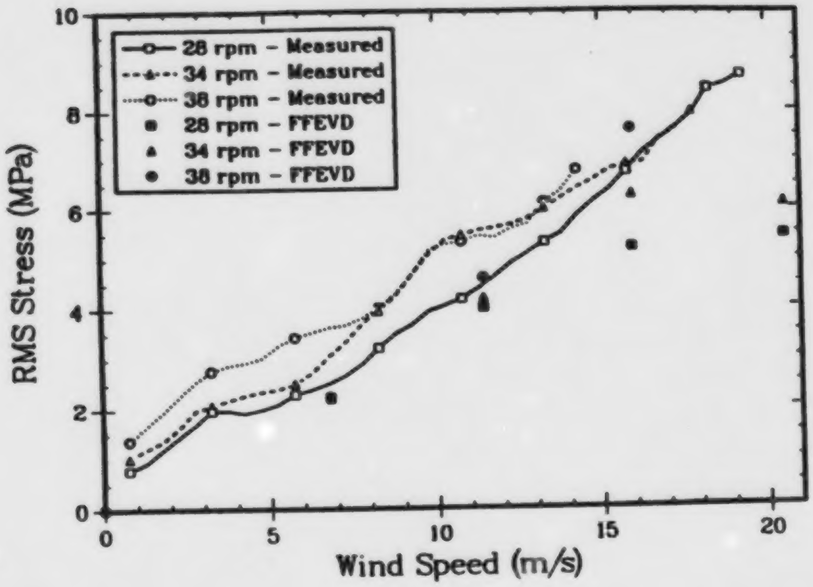


Figure 10. Lower Blade Root Flatwise RMS Stress vs. Wind Speed: Measured and Analytical (FFEVD) Without Turbulence

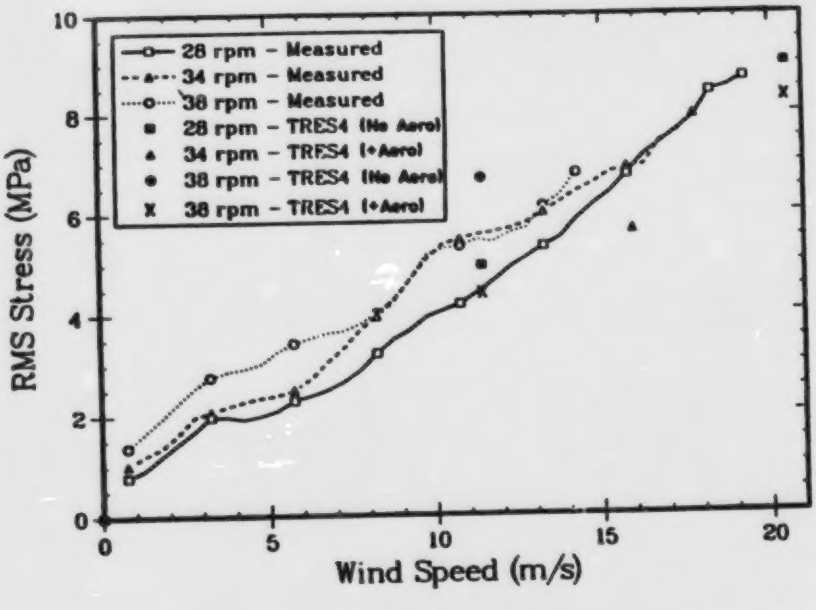


Figure 11. Lower Blade Root Flatwise RMS Stress vs. Wind Speed: Measured and Analytical (TRES4) With Turbulence

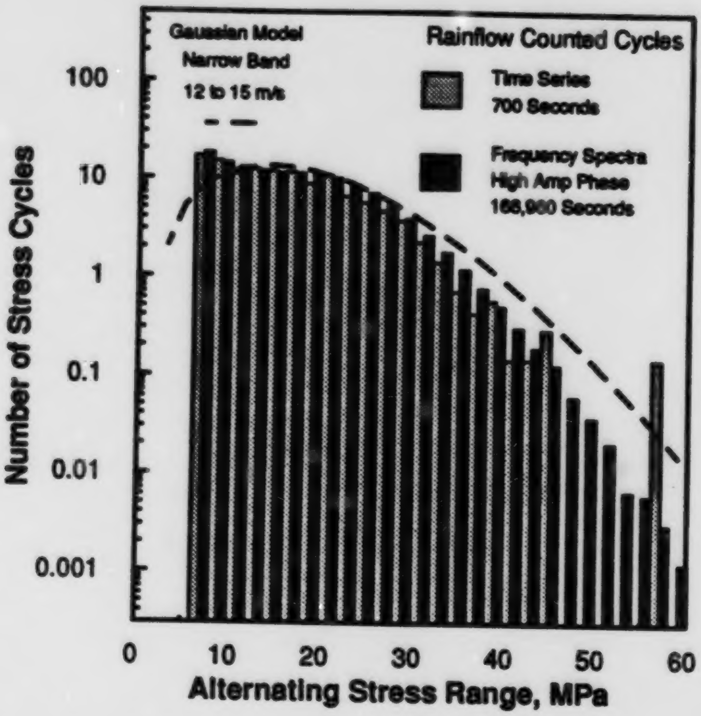


Figure 12. Cycle Counts for the Test Bed Upper Blade-to-Tower Joint (cycle count per 100 seconds).

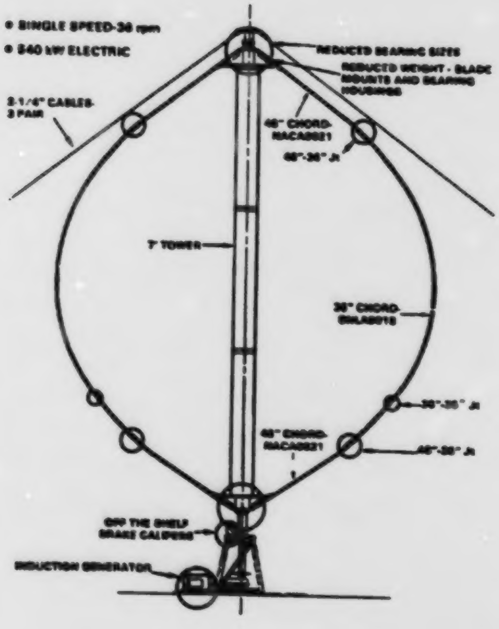

• SINGLE SPEED-38 rpm
• 540 kW ELECTRIC
REDUCED BEARING SIZES
REDUCED WEIGHT - BLADE MOUNTS AND BEARING HOUSINGS
2-1/4" CABLES-3 PAIR
48" CHORD-NACA0021
48"-36" Jt
7' TOWER
36" CHORD-SNLA0018
36"-36" Jt
48" CHORD-NACA0021
48"-36" Jt
OFF THE SHELF BRAKE CALIPERS
INDUCTION GENERATOR

Figure 13. Details of Advanced VAWT Point design

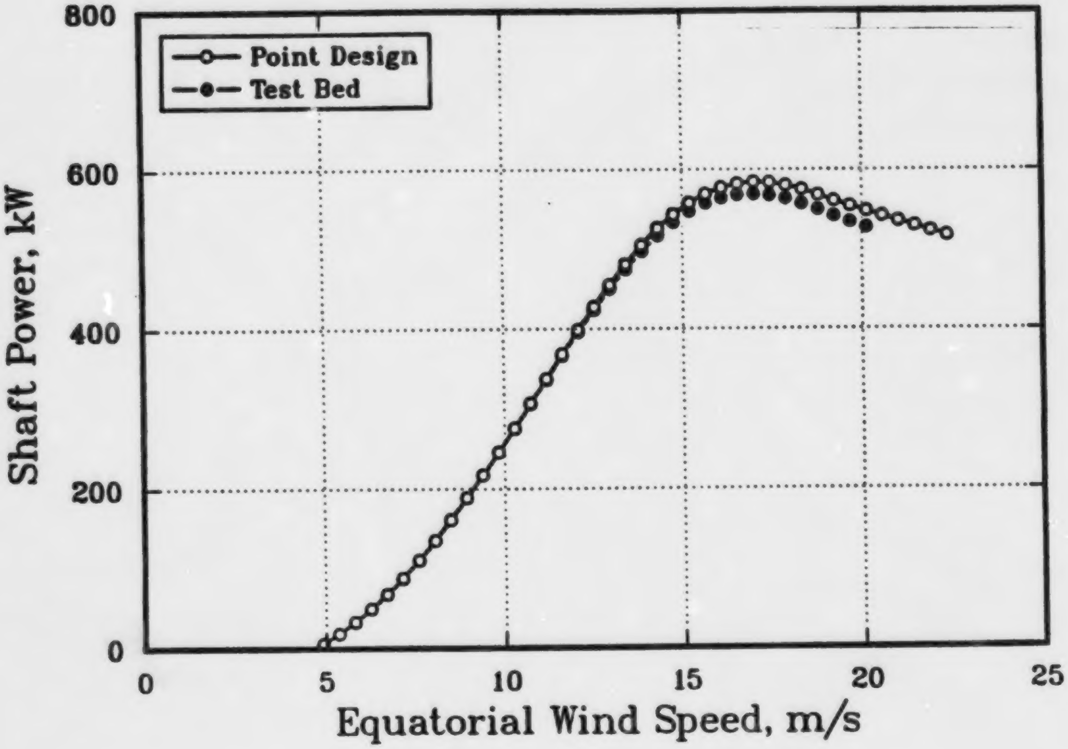
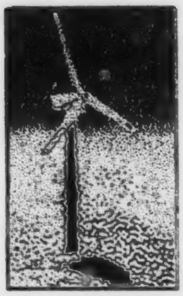


**Figure 14. Predicted Shaft Power at 36 RPM:
34-m Point Design vs. 34-m Test Bed**



BANQUET ADDRESS

Tuesday, November 5

TOWARD A SUSTAINABLE FUTURE

Remarks by David Kilgour, M.P.

Canadian Wind Energy Conference 91
Le Grand Hôtel
Montréal
5 November 1991

It is a pleasure to be here with you tonight to share some thoughts about an issue many thoughtful Canadians find to be of growing importance: the connection between energy problems and the social, environmental, political and economic aspects of our lives. The symptoms of our increasing dependence on dwindling fuel resources have emerged sometimes slowly and gently, sometimes suddenly and painfully.

Canadians now realize that the difficulties associated with supplying and using energy are not temporary; they will continue, and we must learn to deal with them There is also agreement many among Canadians that energy policies can no longer be regarded as fossil-fuel policies only.

Unfortunately, the current federal government has apparently failed to make that connection. While they plead poverty in denying adequate research funds for scientists like many of you gathered here, they continue to dish out hundreds of millions of dollars for fossil fuel mega-projects.

The government is estimated to spend $547 million this year to subsidize the petroleum industry. At the same time, funds to help develop "green" energy technology only reached $35 million. If Ottawa is serious about developing renewable technology and reversing global climate change, then it must put alternative energy research on a level playing field with fossil fuel mega-projects.

It should not be concealed that as an Albertan I am deeply troubled about the plight of our oil and gas industry, especially the livelihoods of about 60,000 people who have lost their jobs in the oil-patch since its more prosperous era in the mid-1980s. As a Canadian and father of four young children, I am equally concerned about the future of our country where energy production and use continue needlessly to damage the environment, harm our health and could make our sluggish economy even more sluggish.

Energy experts agree that fossil resources will continue to be indispensable to the world's energy system until we have a sustainable system built around renewable energy sources. From now on, there should be a slow but continuous change from the heavy reliance on relatively cheap and easy oil and natural gas to an extended period of using fossil fuels that cost more to extract and process and that have potentially larger environmental impacts. We call these "dirty" fuels. Eventually, people will choose not to use fossil fuels because of the availability of cheaper and easier alternatives. That the transition from the use of fossil fuel is inevitable is indisputable.

In the meantime, however, we should increase the efficiency of fossil fuel use, by extracting maximum energy while minimizing harm to the environment. Technologies to ameliorate the effects of fossil-fuel combustion on acid deposition, urban smog and global warming must be pursued. Energy analysts predict that although the world is about to see a switch from coal to natural gas, coal, which accounts for 70% of the energy content of the world's fossil fuel reserves, will remain a sizeable source of fuel. It will be particularly important in the planet's two most populous nations: India and China.

Pollution-control technologies for coal-fired plants or alternative ways to burn coal more cleanly should thus be developed at better than the leisurely current pace. Investments in energy efficiency and conservation, however, can help us reduce fossil fuel demand and reconcile environmental concerns with economic development.

Application of existing efficiency technologies can stretch energy supplies, slow climactic changes and buy us time for the development of alternative energy resources. Improvements in energy efficiency can be implemented much more economically than new supplies of energy can be developed.

Many of the technological solutions needed to increase energy efficiency and conservation already exist. But research and development funded both by the government and the private sector is necessary to push us beyond existing limits. This simple fact does not seem to be recognized by the present federal government, which has eliminated valuable programs to advise industries on how to reduce energy consumption, to inform consumers about the energy efficiency of home appliances, and to assist people to insulate their homes, and so on.

Conservation and alternative energy sources came into sharp focus during the 1970s when unstable political conditions in the Middle East resulted in oil price shocks felt around the world. Oil supply disruptions and price hikes were once again experienced in 1979, as a result of the Iranian revolution. The problem reappeared with the invasion of Kuwait by Iraqi soldiers on August 2, 1990. Consequently, one of the major concerns among the Canadian energy conservers and our alternative energy sector as a whole has been the "disgraceful" neglect and declining roles of support for Canada's alternative energy programs since the unloved Mulroney government came to office in 1984.

The development of significant new energy sources normally takes decades to accomplish. Research cannot be turned on and off from one fiscal year to the next without doing great harm to research efforts. Because of the long lead times for introducing innovations and the long response time of the energy system, decisions taken today would have their full effect only in decades afterwards.

Tory Cuts

The Tory funding of energy conservation and renewable energy activities has shrunk from about $500 million in 1989 to $30 million in 1990-91. This modest spending contrasts sharply with the huge assistance to, for example, our nuclear industry. In other words, the government spends much more promoting the expensive supply option than the cheaper conservation option which is economically and environmentally irrational. They call this Tory economics.

In 1989, the government initiated their cutbacks by the elimination of the National Research Council's Energy Division that was conducting research into solar, wind and fusion energy, hydrogen and other forms of renewable energy. For instance, Canada has a R&D budget for wind energy of around $700,000, whereas the U.S has an annual budget of $21 million and the CEC countries around $150 million annually. In budget cuts announced in April 1989, only six months after being reelected, the government shut down its branch offices in the provinces that provided information and grants for energy conservation and renewable initiatives. This was an unmistakable signal that the federal government was no longer committed to the prudent use of energy, or interested in searching for new and innovative ways of keeping energy costs down.

A recent study done jointly by Friends of the Earth, Pollution Probe, and World Wildlife Fund entitled, The Summit Environmental Accountability Project, concluded that our progress has not only been poor in energy efficiency but also in $C0_2$ emissions over the past five years.

Canadians could largely meet stabilization targets through energy efficiency and conservation measures alone, but the present government has not taken any real steps in this direction. Nor has it estimated the cost of its CO_2 emission abatement strategy. CO_2 emissions dropped by 27 percent in the early 1980s, but over the past 8 years have increased by 8 percent. This is once again at least in part the result of federal cuts to programs which had helped Canadians loosening the iron bond of oil.

In short, subsidizing some energy supply production while cutting back subsidies to energy conservation distorts the competitiveness of energy options and increase the negative environmental impact of energy policy.

There is a wide spectrum of renewable energy sources available to humankind on an inexhaustible basis. We should investigate more thoroughly how large is the energy potential of each of these resources? How much of what is accessible can be used without disturbing the natural system too much?

Renewable Sources

The total energy flows of sunlight intersected by the earth is 178,000 tetrawatts/year (or about 15,000 times the world's present energy supply). Winds, waves and the kinetic energy of ocean currents dissipate roughly 370 tetrawatts/year. Renewable energy sources would seem able to contribute substantially to satisfying the world's thirst for energy and able to do so on an unlimited basis. But our ability to make use of these energy sources depends on the energy supply densities of the various forms, their locations, and the extent to which they can be used economically and without affecting climate and ecology systems significantly or diverting high value land from uses such as food production.

According to some estimates, the potential of renewable energy sources as a whole is comparable to that of fossil resources and of nuclear power by 2030. Each and all of these supply options could provide large amounts of energy in the future, although none is homogenous and the realization of each of these potentials is contingent upon technological progress. Studies of the dynamics of how new technologies replace old ones, indicate that the new technologies generally require a long time to capture a sizeable part of the total energy supply market.

For example, natural gas would take on an ever-increasing share, reaching a peak of about 60% (globally) about 2015 and declining thereafter. I do not find it too surprising, since gas reserves are large, and it is not inconceivable that the problem of long-range transportation of gas could be resolved by that time. Besides, the world's energy systems have great inertia and thus tend to change slowly because it is costly to abandon expensive equipment before its useful life is completed. Hence, even if the world became convinced that a reduction in greenhouse emissions was necessary, the reduction could take decades to accomplish. For instance, if a greenhouse effect actually imposed a sudden constraint on CO_2 emissions, the cost of responding immediately would be extremely high because the non-fossil technologies developed to date are still expensive and limited in supply. Furthermore, the costs would be unevenly distributed and would be most oppressive for developing nations, because they are least able to parry and because their energy needs are growing rapidly.

Because of the long lead times for introducing innovations and the long response time of the energy system, decisions taken today could have their full effect only in the decades to come. Technology, however, will push societies toward sustainability most quickly if policy-makers can agree say, by the mid-1990s, on appropriate global guidelines. The renewables must be used in conjunction with other energy supply systems that would still be needed to provide reserve supplies and barrel loads in grids and to supply poorly endowed regions and districts.

We must keep in mind that it is highly unlikely that we could drive any of the supply systems to their theoretical limits as their effects on our land, water, materials, manpower and climate could perhaps assume such large proportions or to limit the growth of the systems. For example, if solar energy is to meet a large fraction of man's energy needs at some time in the future, it would be able to do so mostly through the use of large, centralized solar systems such as those based on PV applications. According to the Stanford Research Institute experiments, the full-scale deployment of PV systems will probably lead to regional climate changes, such as more humid air, increased precipitation, and increased cloud cover over cities.

The advantages of biomass cannot be taken for granted either. Very large land areas are needed for a harvesting effort capable of ultimately providing up to 6 tetrawatts/year of liquid fuels globally. Added to the needs of humankind for food and natural fibre, fully 1/3 of the biomass growth on land would then be under cultivation. Harvesting even 10% of forest growth requires taking a step from ecological responsibility to ecological engineering. For instance, the introduction of fast-growing monocultures in attempts to improve biomass output for energy purposes is an ecological risk that requires long experience to evaluate. In other words, the use of renewable sources represents a large potential ecological disturbance. To consider relying on them to provide a substantial fraction of our energy supplies is to contemplate undertaking active ecological management on an awesome scale.

Thus, although each individual energy option, be it fossil, nuclear, solar, or the collection of renewable, promises much more energy than current global requirements, realistically probably none of the opportunities will be fully realized in the next 50 years. What we should look for in the foreseeable future is the proper, environmentally benign mix of energy options.

Other countries' interest in wind as an alternative source of energy is impressive. In Denmark, wind energy supplied 2.5% of the country's electricity needs in 1990 and aims at 10% for the year 2000. Other European countries have plans to build large utility wind energy plants. Greece plans to install 30 megawatts this year. Germany and the Netherlands are each installing over 200 megawatts of domestically produced wind turbines before 1995. Sweden is considering the replacement of its nuclear reactors with wind turbines anchored to the sea floor.

During the 1980s, more than 1,660 additional megawatts of wind-electric capacity were installed worldwide. This is the energy equivalent of 3.5 million barrels of oil per year, sufficient to meet the electrical demand of an entire city the size of Los Angeles.

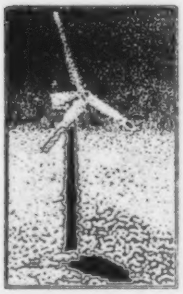
Canada unfortunately lags badly in this respect behind other developed nations although some completed projects proved to be successful. Here in Québec, a wind turbine was installed in Kuujjuak, a small town near Ungava Bay. It was shipped out to Ungava Bay in one container and erected by a crew of three without any heavy equipment in less than an hour. First evaluations indicated that in the period of one year (1987-88) the project generated 77,000 kw/hours. A couple of hundred of them would practically equal what the province would get in kilowatts of electricity from harnessing the Great Whale River.

By the wind sectors' own admission, a deterrent to wider application of wind energy lies in the lack of interest in and support of government towards the development of such initiative. It's not economics of wind energy that is the real barrier but lack of political will. The Tory government does not seem to recognize wind energy as an environmentally benign energy supply option, that generates employment and is socially acceptable. They are equally unwilling to become more involved with provincial and private utilities to promote the development of new, more environmentally friendly energy technologies.

Part of the problem, however, is that we do not have a strong, coherent, organized lobby for wind and other renewable energy sources. As one witness representing the Solar Energy Society put it at the hearings of the Standing Committee on Energy last year, the renewable energy sector "was stronger 5 years ago than it is now. A number of flagship companies have gone out of business... There have been a number of survivors... but it is very difficult for them to make a coherent case on an ongoing basis that the federal government should intervene on their behalf."

It seems that the Canadian public, increasingly worried about the environment, has taken the initiative and put pressure to change the present attitudes in our political and administrative management. We may even witness an emergence of a political force resembling the Green Party phenomenon in Europe that successfully influences the policy-making process.

Merci.



BLADE DEVELOPMENTS & AERODYNAMICS

SERI ADVANCED WIND TURBINE BLADES

Presented to

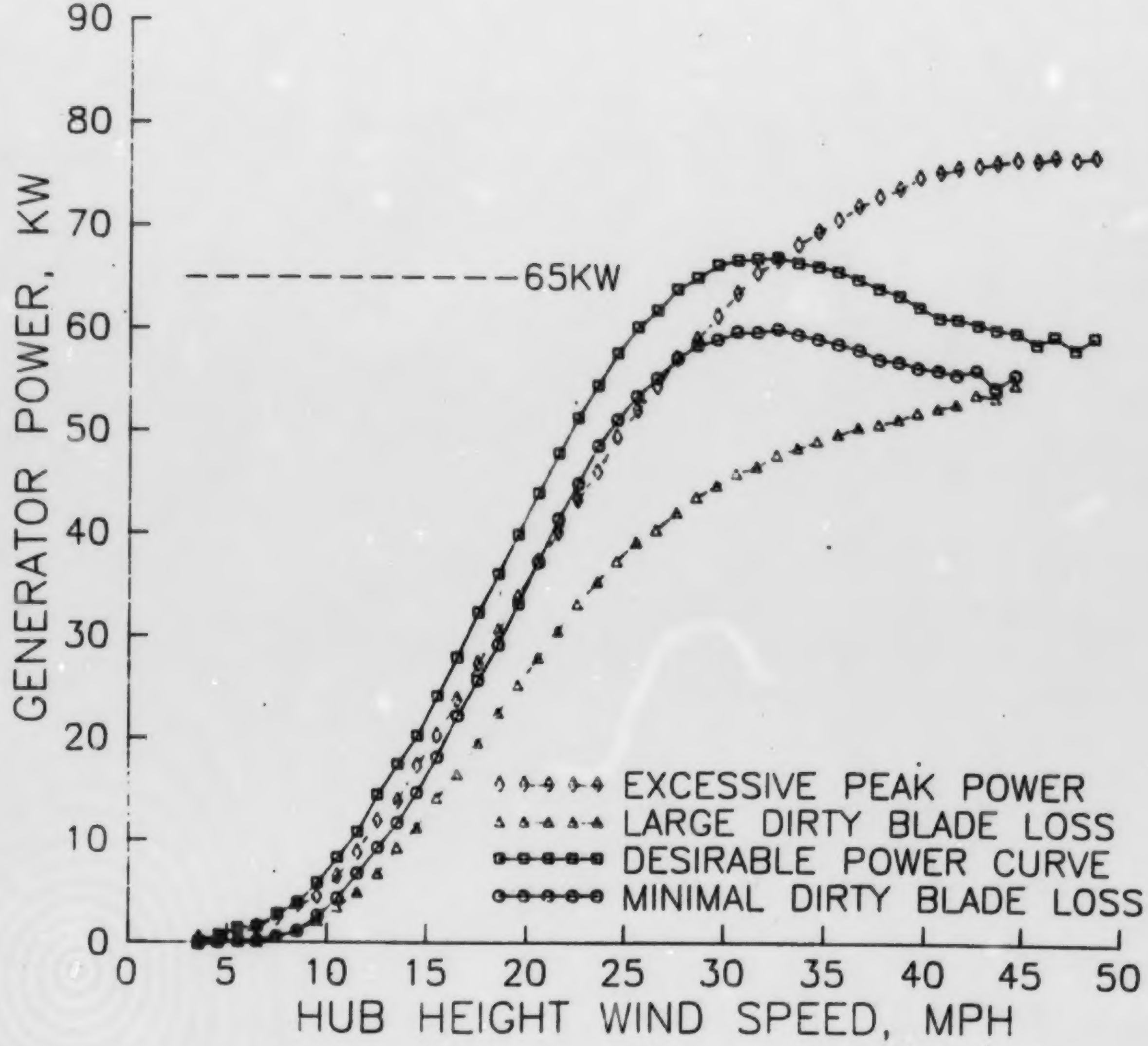
Canadian Wind Energy Conference '91

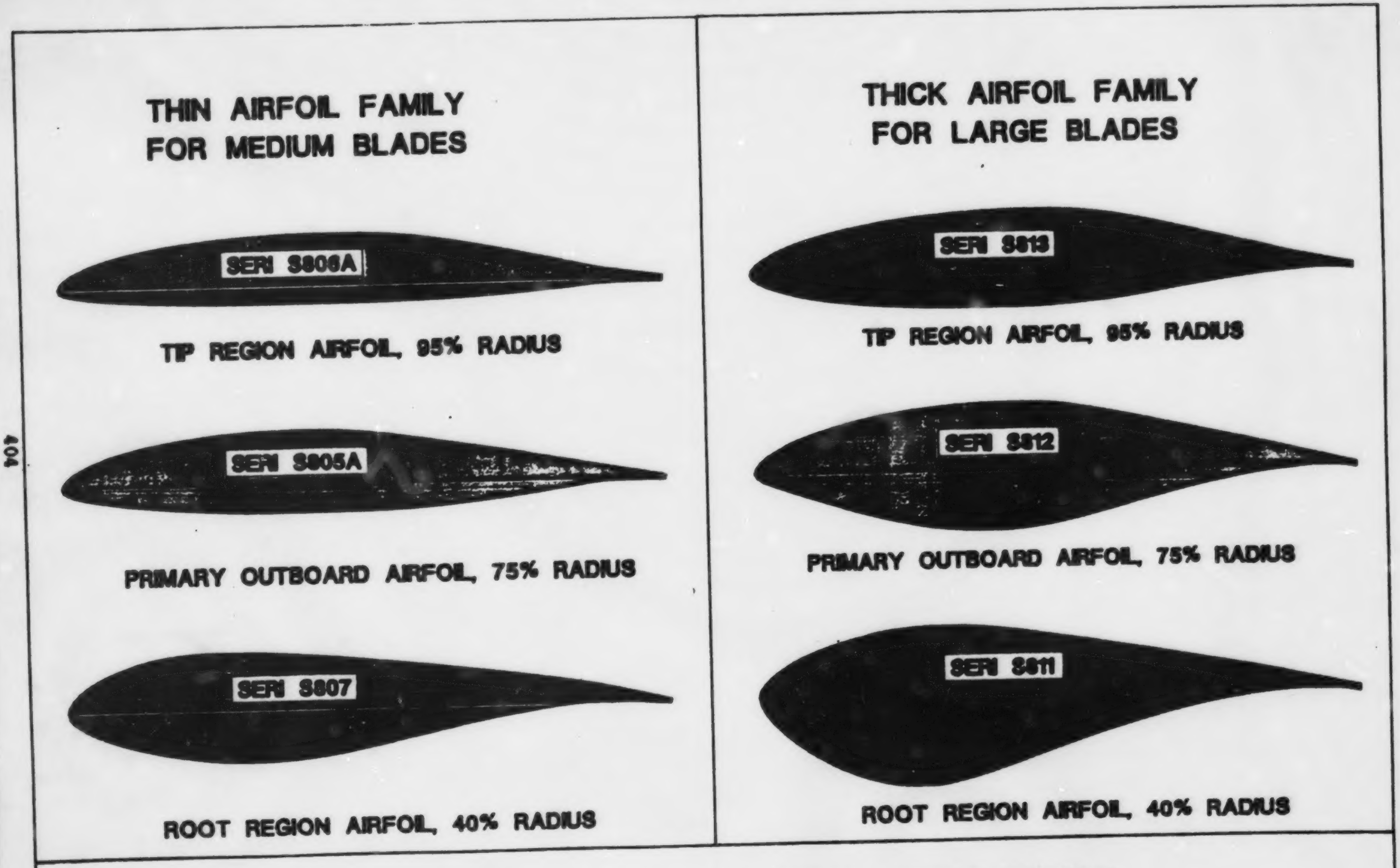
November 5-7, 1991
Le Grand Hotel, Montreal, Quebec

by

James Tangler
National Renewable Energy Laboratory
Golden, Colorado

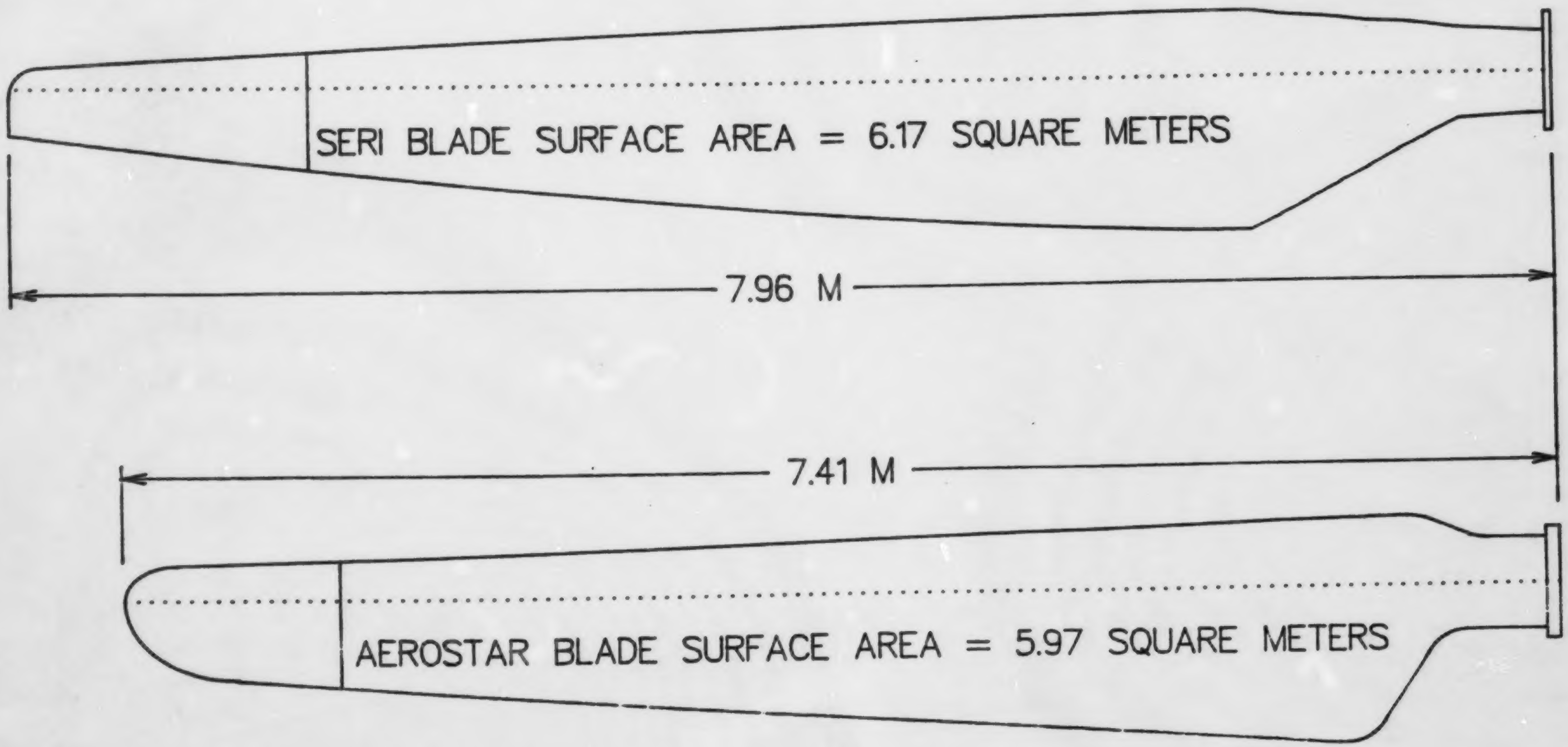
MICON 65 – POWER OUTPUT PROBLEMS



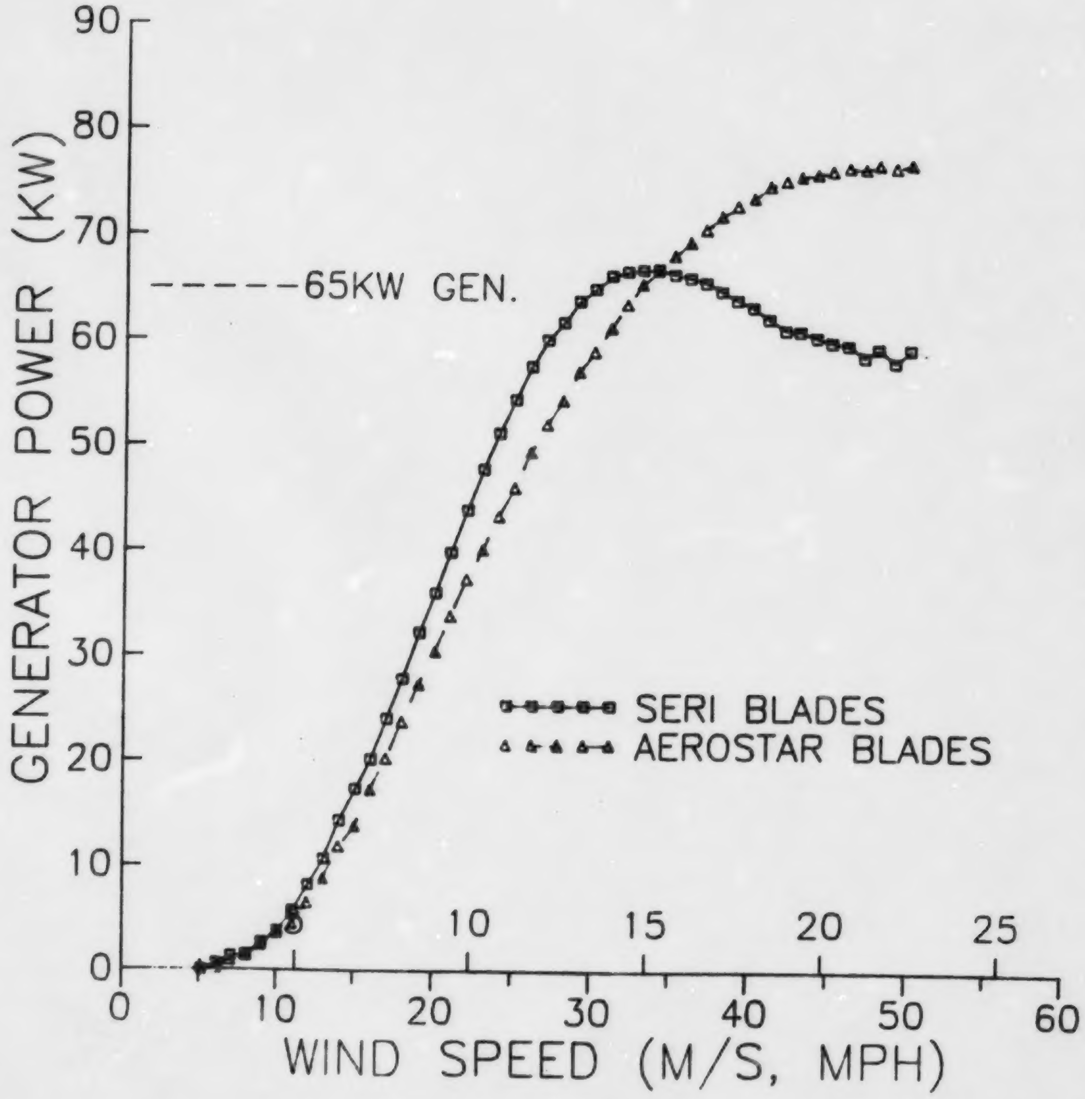

THIN AIRFOIL FAMILY
FOR MEDIUM BLADES
SERI S806A
TIP REGION AIRFOIL, 95% RADIUS
SERI S805A
PRIMARY OUTBOARD AIRFOIL, 75% RADIUS
SERI S807
ROOT REGION AIRFOIL, 40% RADIUS
THICK AIRFOIL FAMILY
FOR LARGE BLADES
SERI S813
TIP REGION AIRFOIL, 95% RADIUS
SERI S812
PRIMARY OUTBOARD AIRFOIL, 75% RADIUS
SERI S811
ROOT REGION AIRFOIL, 40% RADIUS

SPECIAL PURPOSE THIN AND THICK AIRFOIL FAMILY

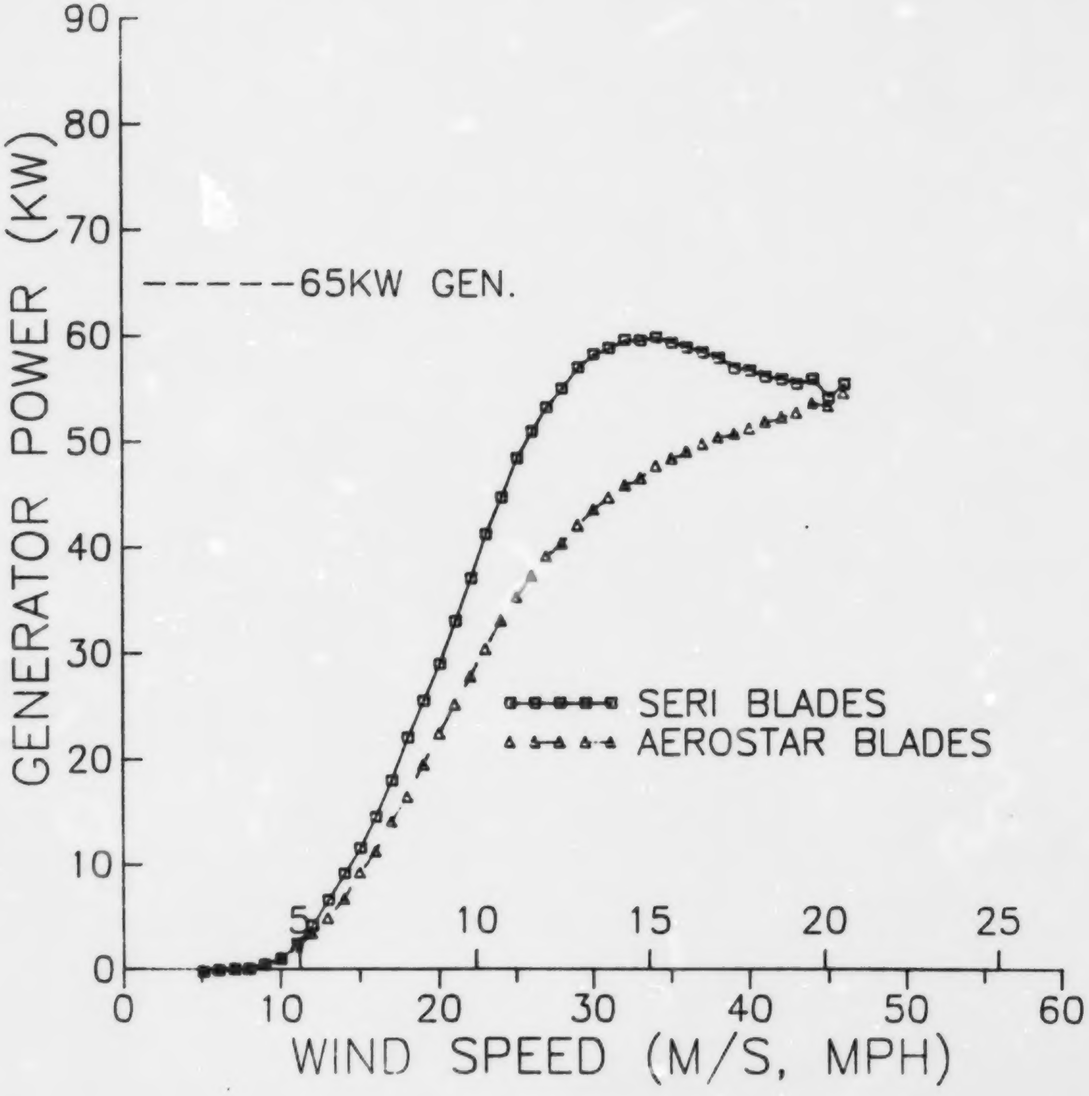
SERI / AEROSTAR BLADE PLANFORM COMPARISON


SERI BLADE SURFACE AREA = 6.17 SQUARE METERS
7.96 M
7.41 M
AEROSTAR BLADE SURFACE AREA = 5.97 SQUARE METERS

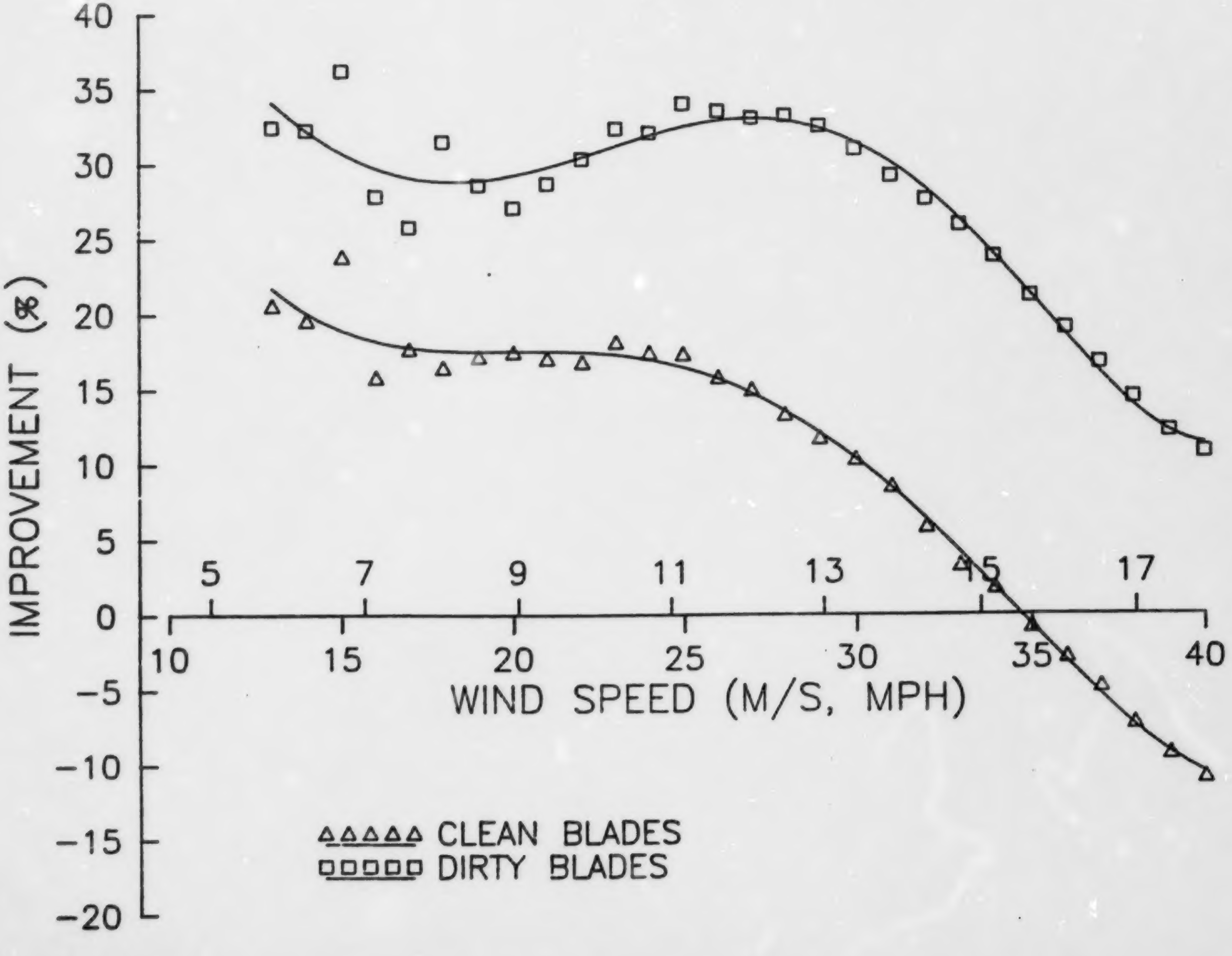
CLEAN BLADE MICON 65/13 GENERATOR POWER OUTPUT



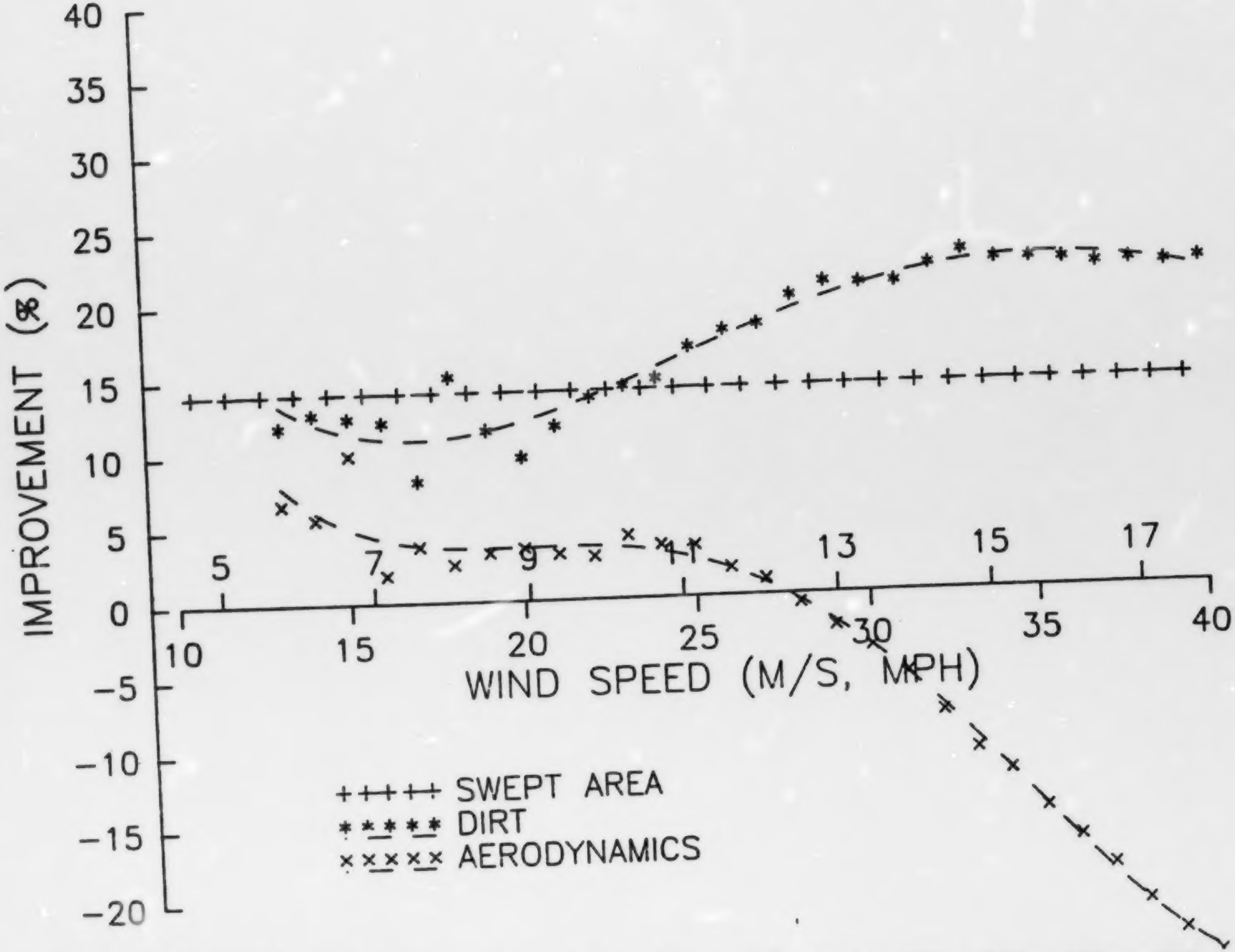
DIRTY BLADE MICON 65/13 GENERATOR POWER OUTPUT



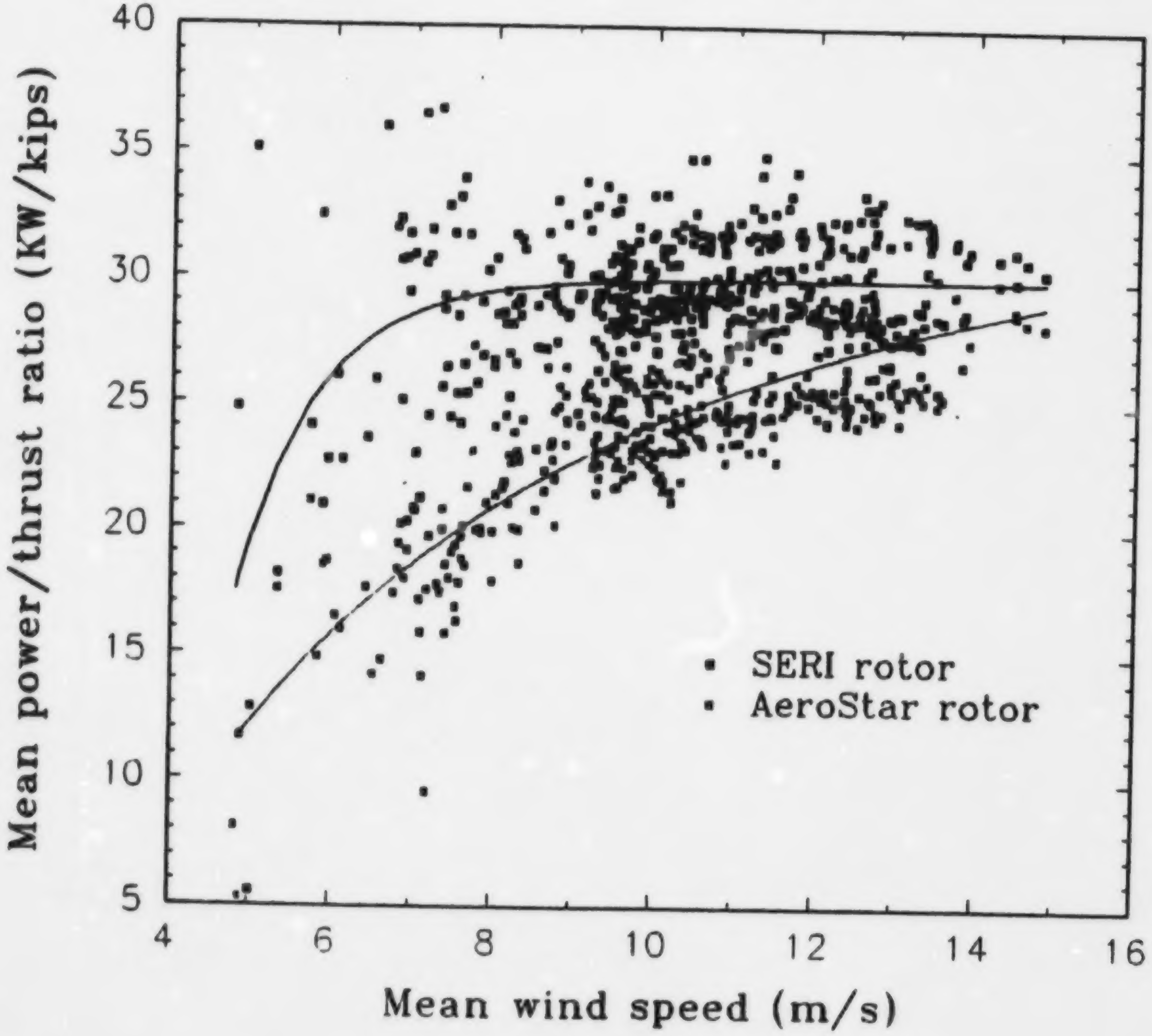
GENERATOR POWER OUTPUT IMPROVEMENTS
(SERI BLADE OVER AEROSTAR BLADE)



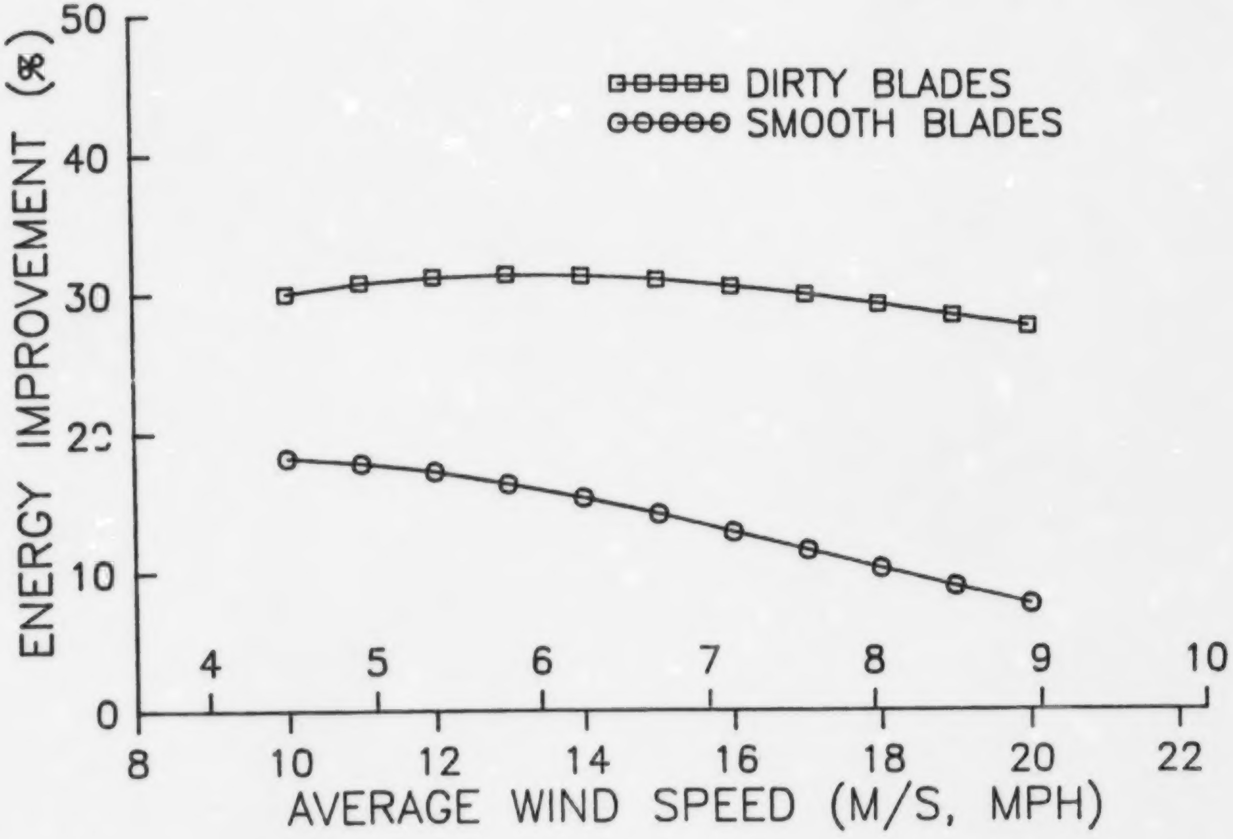
GENERATOR POWER OUTPUT IMPROVEMENTS
(SERI BLADE OVER AEROSTAR BLADE)



COMPARISON OF SERI AND AEROSTAR POWER-TO-THRUST RATIOS



ANNUAL ENERGY IMPROVEMENT, %
Rayleigh Distribution: SERI vs AeroStar



CONCLUSIONS

SERI Advanced Wind Turbine Blades provide:

- Peak power regulation
- Minimal roughness sensitivity
- Greater annual energy output
- Higher power-to-thrust ratios

THREE DIMENSIONAL ANALYSIS OF VERTICAL-AXIS WIND TURBINES

BY

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Ecole Polytechnique de montreal

Paper presented at:

The Seventh Annual Wind Energy Conference and
Exhibition - Canadian Wind Energy Association
Montreal, Quebec, November 4-7, 1991

THREE DIMENSIONAL ANALYSIS OF VERTICAL-AXIS WIND TURBINES

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Montréal, Québec, Canada, H3C 3A7

ABSTRACT

In this paper, the investigation of the flow field of a vertical-axis wind turbines based on the solution of the steady, incompressible, laminar Navier-Stokes equations in cylindrical coordinates is presented. The flow equations, written in conservation law form, are discretized using a control volume approach and the resulting elliptic equations are solved by a line-by-line method combining the TriDiagonal Matrix Algorithm (TDMA) and the Gauss-Seidel method. The numerical procedure used for solving the flow governing equations is based on Patankar's SIMPLER algorithm. The motion of blades are time averaged and introduced through the source terms into the momentum equations.

Some preliminary results dealing with the determination of the world size (the size of the computational domain), the convergence of the numerical model are first presented, then normal force coefficient and angle of attack are computed and compared with experimental results.

NOMENCLATURE

c	blade chord, m
C_D	drag coefficient of blade airfoil section
C_L	lift coefficient of blade airfoil section
C_N	normal force coefficient of blade airfoil section
C_P	power coefficient of the turbine
C_T	tangential force coefficient of blade airfoil section
$\vec{F}$	resultant aerodynamic force, N
L	blade length, m
n, θ, s	coordinate system attached to the blade
N	number of blades
p	static pressure, Pa
r, θ, z	cylindrical coordinate system attached to the blade
R	rotor radius at a certain level, m
R_{eq}	rotor radius at the equator, m
S	rotor swept area, m^2
S_r, S_θ, S_z	source terms in the momentum equations
T_0	torque generated at the center of the turbine, N.m
u, v, w	velocity components in the r,Θ,z directions, m/s
$\vec{V}_{abs}$	absolute velocity of the wind, m/s
V_n	component of V_{abs} in the n-direction, m/s
$\vec{V}_{rel}$	relative velocity, m/s
V_∞	freestream wind velocity, m/s
X_{eq}	tip speed ratio at the equator
α	local angle of attack, deg
θ	azimuthal angle, deg
μ	dynamic viscosity, Pa.s
ρ	density, kg/m^3
σ	rotor solidity (NcL/S)
ω	rotor rotational speed, s^{-1}

Superscripts and Subscripts

eq	equatorial values
∞	freestream conditions

1. INTRODUCTION

Wind energy is considered to be a promising renewable energy source, particularly for remote areas, like islands and mountanous regions. Advances in large-scale wind energy systems, significant cost reductions, more efficient manufacturing techniques and increasing technical experience have contributed greatly to the use of wind energy. Although invented in 1931, (1) the Darrieus rotor did not see extensive development until 1970's during the world-wide oil crisis where a considerable amount of work has been done with regard to aerodynamic performance prediction methods for vertical-axis wind turbines.

Over the past decade, significant progress has been made in the development of the aerodynamic models for studying vertical-axis wind turbines. Aerodynamic analysis of vertical-axis wind turbines is based on the several methods which can be classified into two major categories: momentum models and vortex models. An updated review of the state-of-the-art of such methods, including the appropriate references is provided by Strickland (2,3) and Paraschivoiu (4).

The fundamental objective of all aerodynamic prediction models for the Darrieus rotor is to evaluate the velocity field around the turbine since such knowledge allows the calculation of all the forces on the blade and the power generated by the turbine. In general all of the methods, described above, give satisfactory accuracy in overall performance prediction for design purposes but somewhat different results for detailed blade load distributions.

2. COMPUTATIONAL PROCEDURE

The numerical model is based on the solution of the steady laminar incompressible Navier-Stokes equations to obtain the vector velocity field. This approach was first developed by Rajagopalan (5) for the Euler equations and extended to Navier-Stokes equations (6).

In this formulation, the effect of the spinning blades is simulated by distributing source terms in the ring of control volumes that lie in the path of the turbine blades. The essentials of this analysis are presented in the following subsections.

2.1 Flow field modeling

Some general features of the Sandia 17-m vertical-axis wind turbine are presented on Fig. 1. The top of view of the rotor according to the section (A-A) shown by Fig. 2 gives:

$$\vec{V}_{rel}=(V_n\vec{e}_n+V_\theta'\vec{e}_\theta)=(\vec{V}_{abs}\vec{e}_n)\vec{e}_n+(\vec{V}_{abs}\vec{e}_\theta-\omega r)\vec{e}_\theta$$

where:

$$V_n=(u\cos\delta+v\sin\delta) \quad \text{and} \quad V'_\theta=(v-\omega r)$$

Since ωr, the linear velocity of the turbine blade, is known the only unknown in the above equation is $\vec{V}_{abs}$. Solution of the velocity field would yield the knowledge of all the quantities of interest.

With the assumptions stated previously, the governing equations for the flow field of a vertical-axis wind turbine are:

mass:

$$\frac{1}{r}\ \frac{\partial}{\partial r}(\rho r u)+\frac{1}{r}\ \frac{\partial}{\partial\theta}(\rho v)+\frac{\partial}{\partial z}(\rho w) = 0$$

r-momentum:

$$\frac{1}{r}\frac{\partial}{\partial r}r(\rho uu-\mu\frac{\partial u}{\partial r})+\frac{1}{r}\frac{\partial}{\partial\theta}(\rho uv-\mu\frac{\partial u}{r\partial\theta})+\frac{\partial}{\partial z}(\rho uw-\mu\frac{\partial u}{\partial z})=-\frac{\partial p}{\partial r}+b_r$$

Θ-momentum:

$$\frac{1}{r}\frac{\partial}{\partial r}r(\rho uv-\mu\frac{\partial v}{\partial r})+\frac{1}{r}\frac{\partial}{\partial\theta}(\rho vv-\mu\frac{\partial v}{r\partial\theta})+\frac{\partial}{\partial z}(\rho vw-\mu\frac{\partial v}{\partial z})=-\frac{\partial p}{r\partial\theta}+b_\theta$$

z-momentum:

$$\frac{1}{r}\frac{\partial}{\partial r}r(\rho wu-\mu\frac{\partial w}{\partial r})+\frac{1}{r}\frac{\partial}{\partial\theta}(\rho wv-\mu\frac{\partial w}{r\partial\theta})+\frac{\partial}{\partial z}(\rho ww-\mu\frac{\partial w}{\partial z})=-\frac{\partial p}{\partial z}$$

The discretization method used to solve the governing equations is a successful method based on the finite volume method (FVM) proposed by Patankar (7) on the cartesian coordinates system. In the simulation of the incompressible flow, the basic equations are generally expressed as the conservation of physical values as mass or momentum. According to this method, the governing equations are integrated over each control volume cell to derive the discretized equations from them. For a velocity-pressure coupled flows, a staggered grid system is known to give more realistic solutions and is adopted in the present study. The computational domain in cylindrical coordinates system is subdivided into control volumes by series of line orthogonal to r, θ, and z coordinates directions. Typical control volume cells are shown by Fig. 3. The calculating method based on the control volume approach used here is the widely known "SIMPLER" algorithm. A clear and detailed description of "SIMPLER" together with the improvements that have evolved since 1972, has been provided by Patankar (7,8). Once the control volume discretization is completed, the procedure for solving the corresponding set of algebraic equations relies on the common practice of solving them by a standard line-by-line method in conjunction with the Gauss-Seidel method.

2.2 Turbine modeling

The motion of vertical-axis wind turbine blades introduce primarily a change on the local momentum of the fluid due to the forces generated by the rotating blades. Thus, an obvious place to introduce the action of the blades in the governing equations of the flow field is through the source terms on the momentum equations namely S_r, S_θ, and S_z. These source terms are valid for all the computational cells that lie in the path of the turbine blades.

According to Fig. 2, forces due to lift and drag per unit of span along the blade in the direction of e_n is given by:

$$s_n=(c\ 1)(\rho\frac{V_{rel}^2}{2})(C_L\cos\alpha+C_D\sin\alpha)$$

where:

$$V_{rel}=(V_n^2+V_\theta'^2)^{1/2}$$

Eliminating α with the following equations:

$$V_n=V_{rel}\sin\alpha \qquad V_\theta'=-V_{rel}\cos\alpha$$

one obtains,

$$s_n=\frac{(c\rho V_{rel})}{2}(-C_LV_\theta'+C_DV_n)$$

Similarly s_θ, the force in the θ-direction is given by:

$$s_\theta = \frac{(c\rho V_{rel})}{2}(C_L V_n + C_D V_\theta')$$

Time averaging s_n and s_θ for N blades passing through a given computational cell yields the time averaged forces felt by the blades S_n and S_θ in the normal and tangential coordinate directions respectively:

$$S_n = (\frac{c\rho V_{rel}}{2})(\frac{N\Delta\theta}{2\pi})(-C_L V_\theta' + C_D V_n)$$

$$S_\theta = (\frac{c\rho V_{rel}}{2})(\frac{N\Delta\theta}{2\pi})(C_L V_n + C_D V_\theta')$$

where $(N\Delta\theta/2\pi)$ is the time averaging factor that denotes the ratio of time spent by N blades in traversing through a given cell to time taken by a blade to go through one complete revolution.

Thus, the forces in the r and z directions are:

$$S_r = S_n \cos\delta \qquad S_z = S_n \sin\delta$$

Finally, the time averaged source terms S_r, S_θ and S_z in a convenient form suitable for using the numerical algorithm yields to:

$$S_r = W\cos\delta(C_D u\cos\delta - C_L V_\theta' + C_D w\sin\delta)$$

$$S_\theta = W(C_D v + C_L V_n - C_D\ \omega r)$$

$$S_z = W\ \sin\delta(C_D\ w\sin\delta - C_L\ V_\theta' + C_D\ u\cos\delta)$$

where $W = Nc\rho V_{rel}\Delta\theta/4\pi$

These are forces felt by the blades per unit of span, and thus are substracted in the momentum equations to effect an equal but opposite reaction on the fluid at a specific cell. All forces and power computations are integrated for the grid points that lie in the path of the blades. if $\vec{F}$ is the resultant aerodynamic force felt by the blades then:

$$\vec{F}=S_r\vec{e}_r+S_\theta\vec{e}_\theta+S_z\vec{e}_z$$

$$T_0=\sum\vec{r}\times\vec{F}$$

$$C_p=\frac{T_0\omega}{(0.5\rho V_\infty\ 2RH)}$$

3. RESULTS AND DISCUSSION

At the first stage of the study, only preliminary results for validating the computational procedure are presented. Thus, for the turbine problem it was necessary to first establish the size of the computational domain which is refered to as the world size. The domain was considered to be large or accurate enough when the power coefficient reached an asymptotic value. This exercise was carried on the Sandia 17-m rotating at RPM=42.2 and X_{eq}=6.12. This value was used instead of other experimental values to avoid the effect of dynamic stall phenomena on the computed results.

As shown in Fig. 4, C_p reached its asymptotic value at a world size of about 60 R_{eq}. A same exercise was carried out for the θ-grid size which is illustrated by Fig. 5. According to this Figure, a minimum of 40 points are needed to get a sufficient computational grid in θ-direction. For the z-direction, Fig. 6 shows that 26 points at least were necessary to an asymptotic value for C_p. Thus, for all following computations, the fineness of the grid was maintained at (66x48x26) points. A last feature about Fig. 6 is that at the end of the optimisation exercise, the calculated value of the power coefficient $C_p$is almost equal to the corresponding experimental data ($C_{P(exp)}$=0.387).

In Fig. 7, a convergence history of C_P with the number of iterations is presented and as seen in this figure, a convergence solution is obtained as early as 100 iterations and even before that. In general, the calculation were taken to 250 iterations for an insurance of the convergence behavior.

A second level of this investigation deals with the presentation of some aerodynamic characteristics. Fig. 8 shows a comparison between values of normal force coefficient C_N and the corresponding experimental data (9) for Sandia 17-m wind turbine rotating at 38.7 rpm for a tip-speed ratio of 4.60. From preliminary comparison it became apparent that results show a close agreement with respect to experimental data in both regions (upwind and downwind zones) even if the extreme part of the downwind zone show some light differences.

In Figure 9, typical variation of the angle of attack vs the azimuth for the same conditions is presented. Here also, a good agreement is noticed from this figure even if the same part is subject to some slight differences.

In conclusion, a new computational procedure to analyse the performance of a three-dimensional vertical-axis wind turbine has been developed. Analysis of the first computed results in regards to the corresponding experimental data are very encouraging. For next steps, considerable improvement could also be achieved for future predictions by the use of dynamic-stall model (10) during dynamic-stall regimes.

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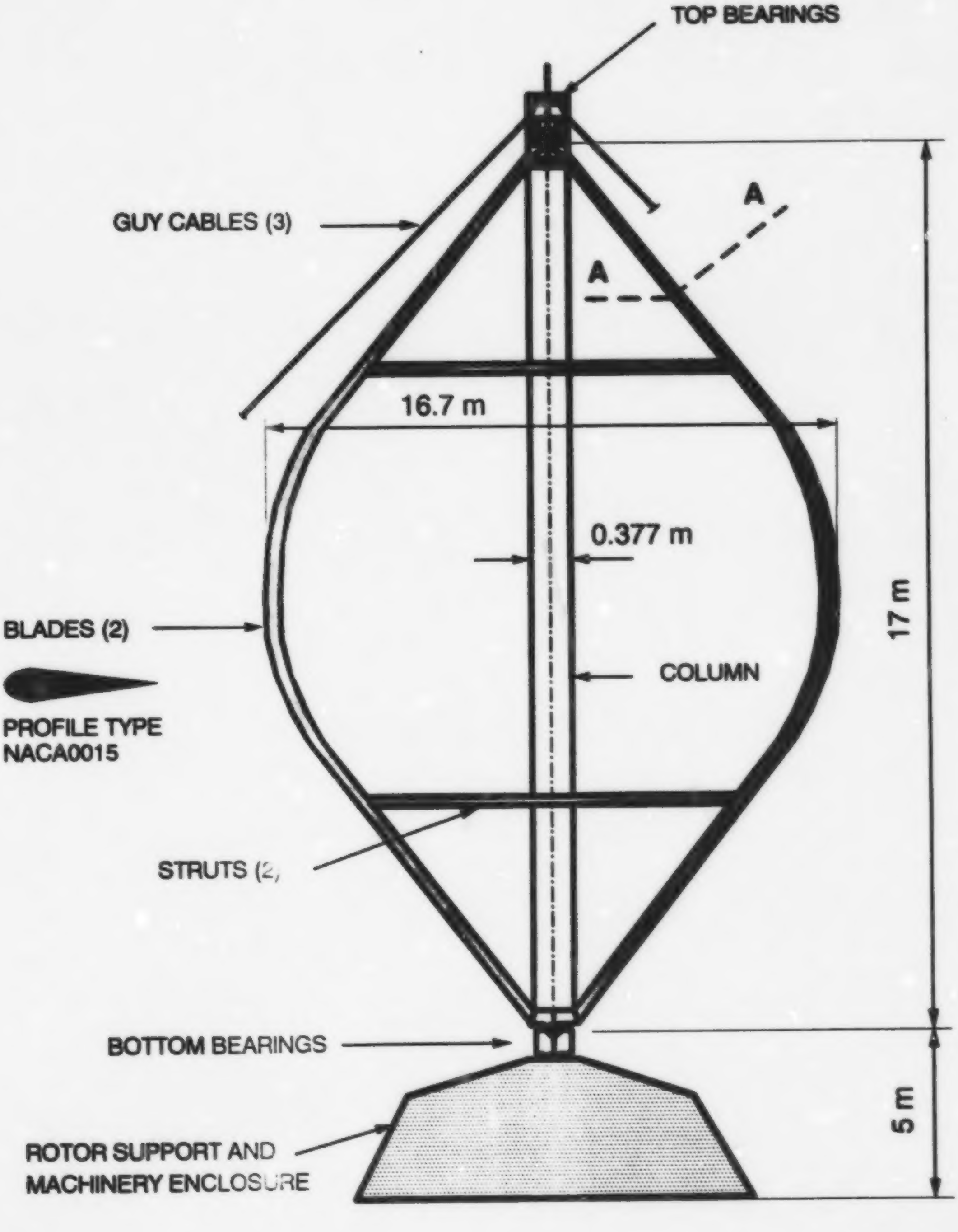
TOP BEARINGS
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0.377 m
17 m
BLADES (2)
COLUMN
PROFILE TYPE
NACA0015
STRUTS (2)
BOTTOM BEARINGS
5 m
ROTOR SUPPORT AND
MACHINERY ENCLOSURE

Fig. 1 General configuration of Sandia 17-m VAWT

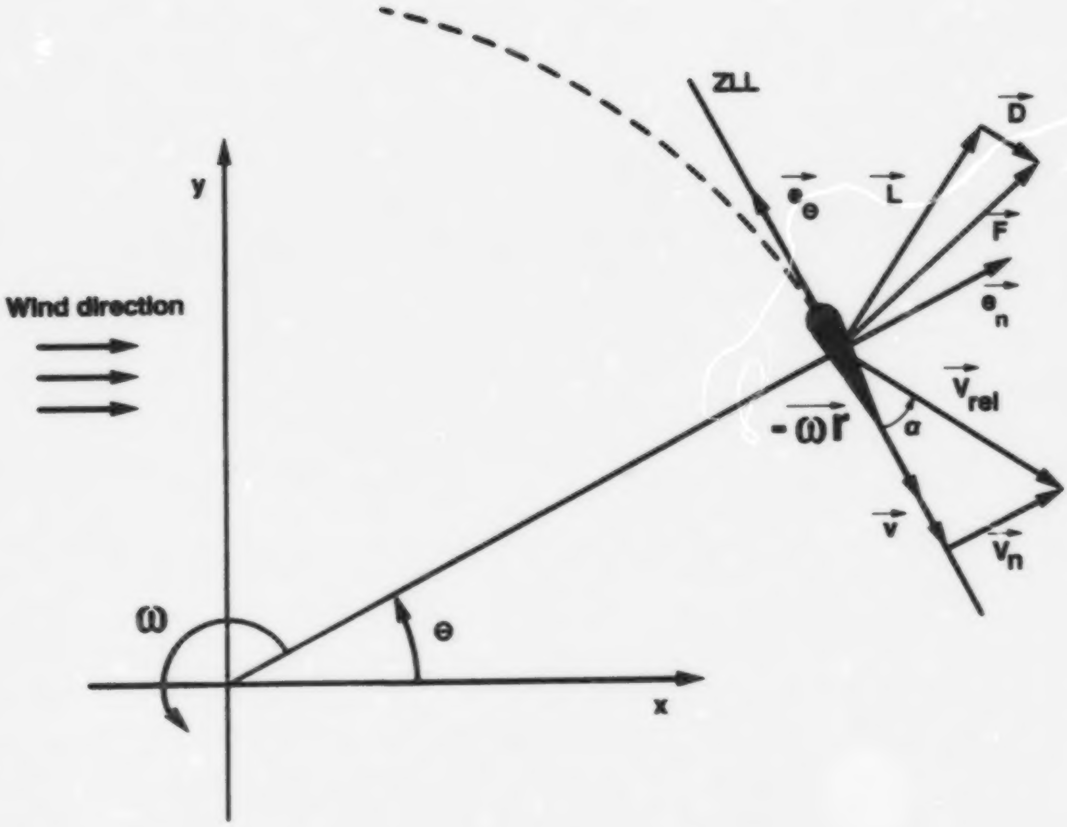
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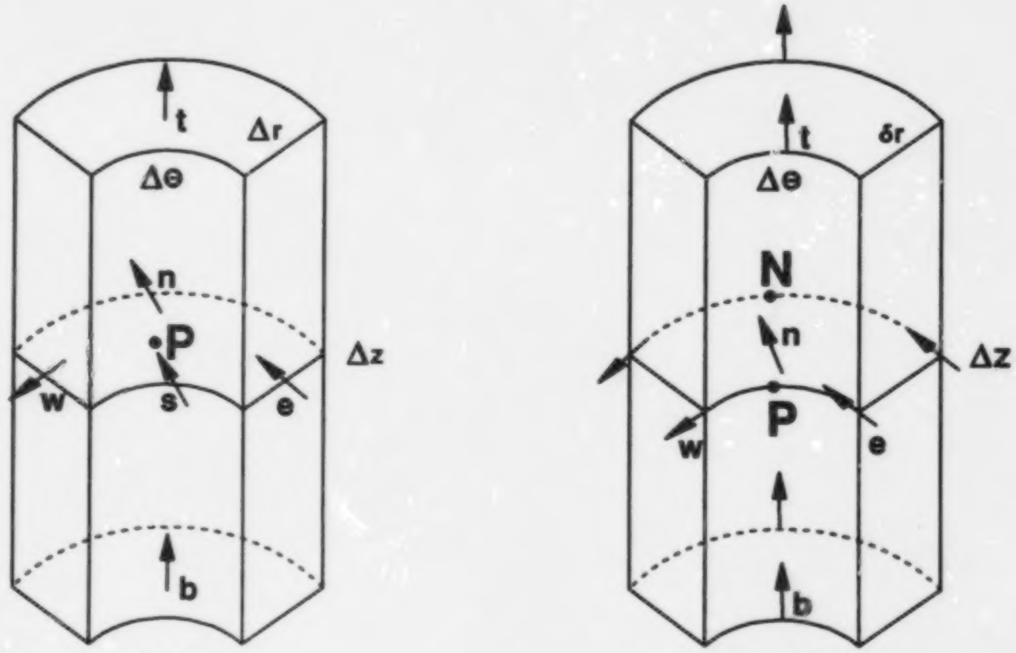
Fig. 2 Angles, velocity vectors and forces (section A-A)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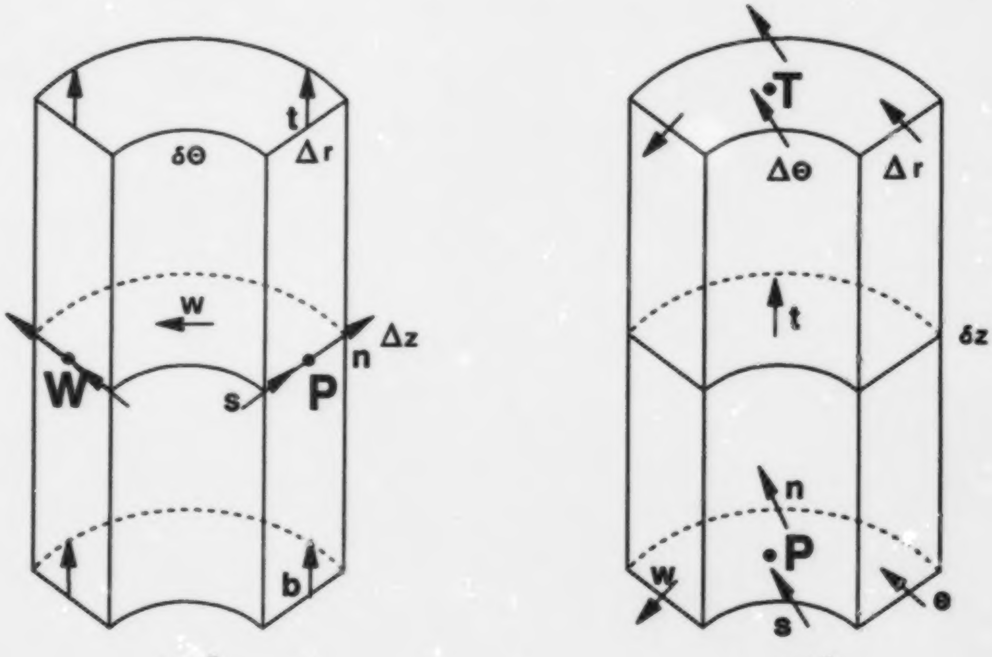
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Fig. 3 Typical control volume cells for u,v,w and p

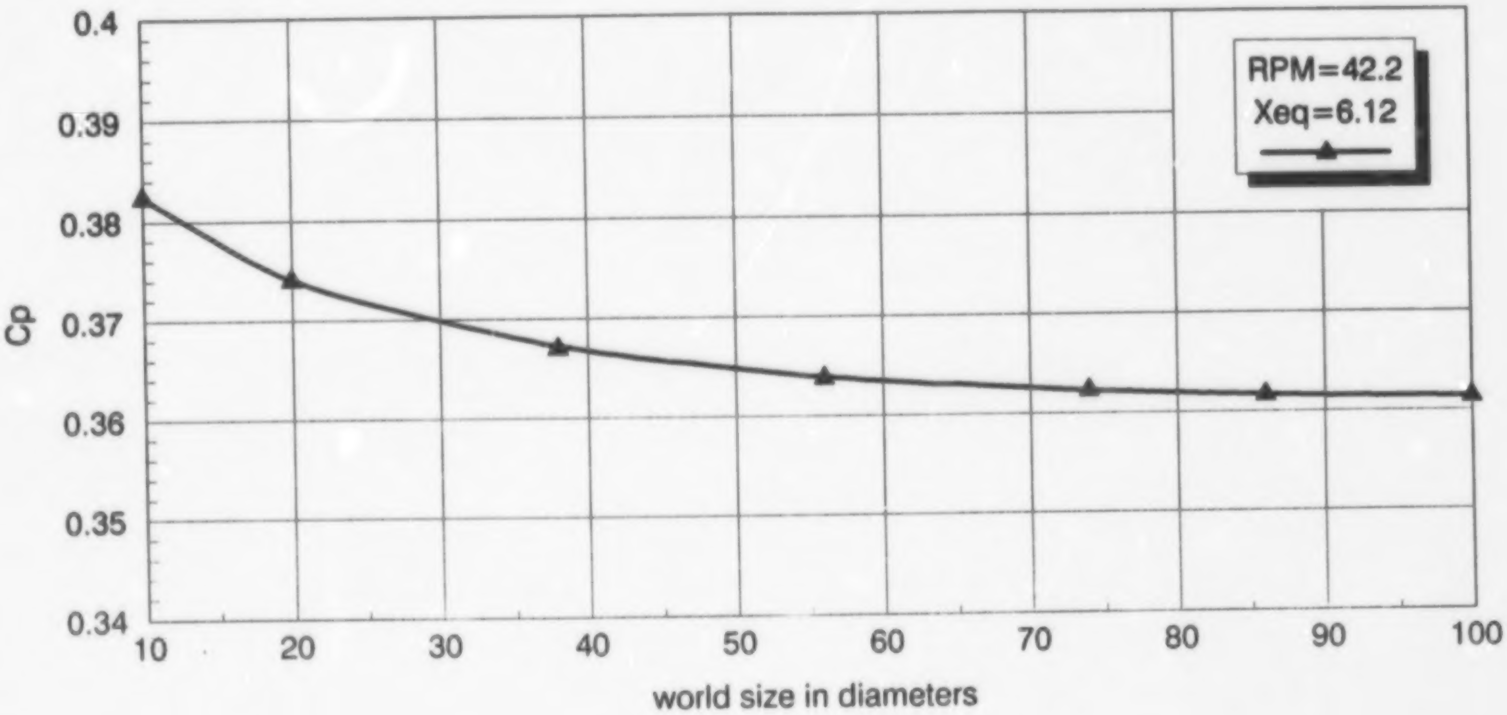

Fig. 4 Effect of world size in r-direction on Cp

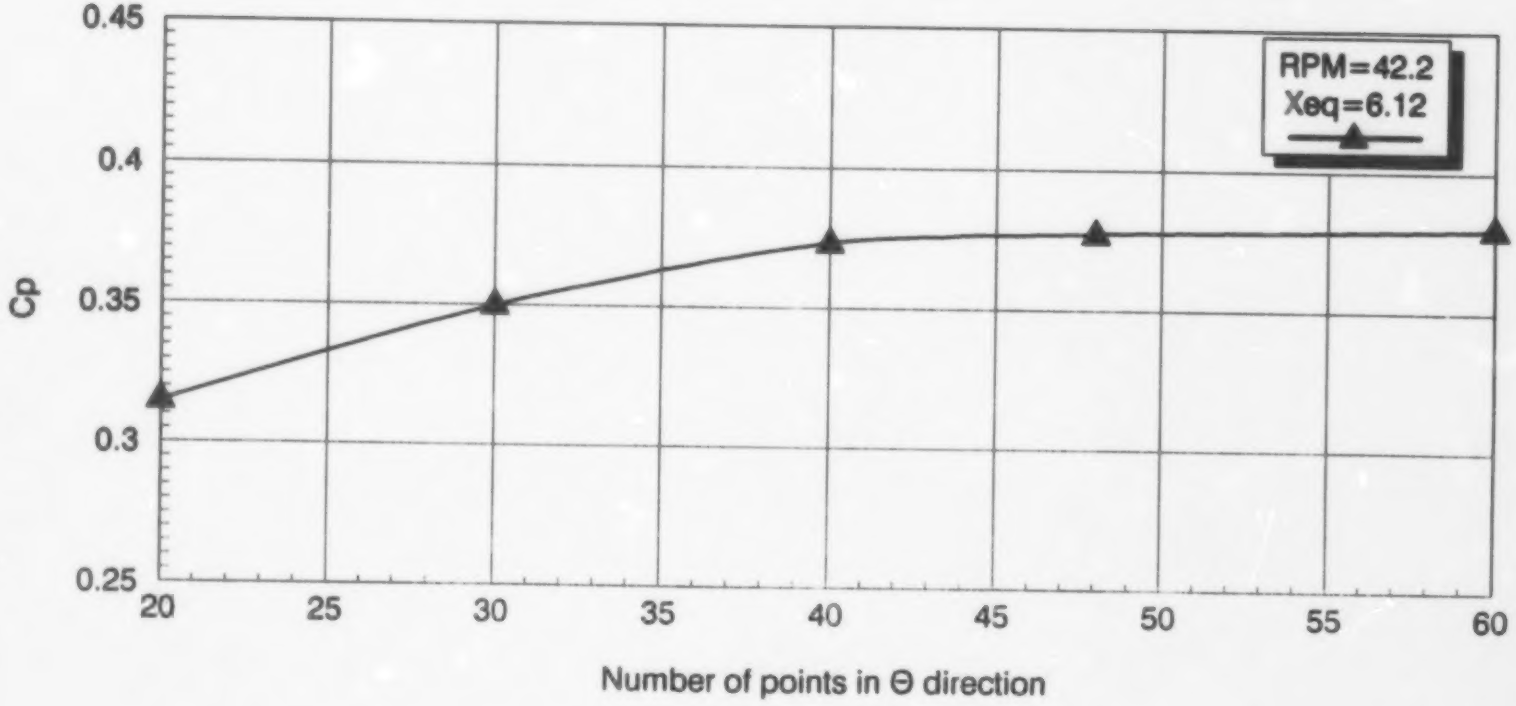

Fig. 5 Effect of grid points in-Θ direction on Cp

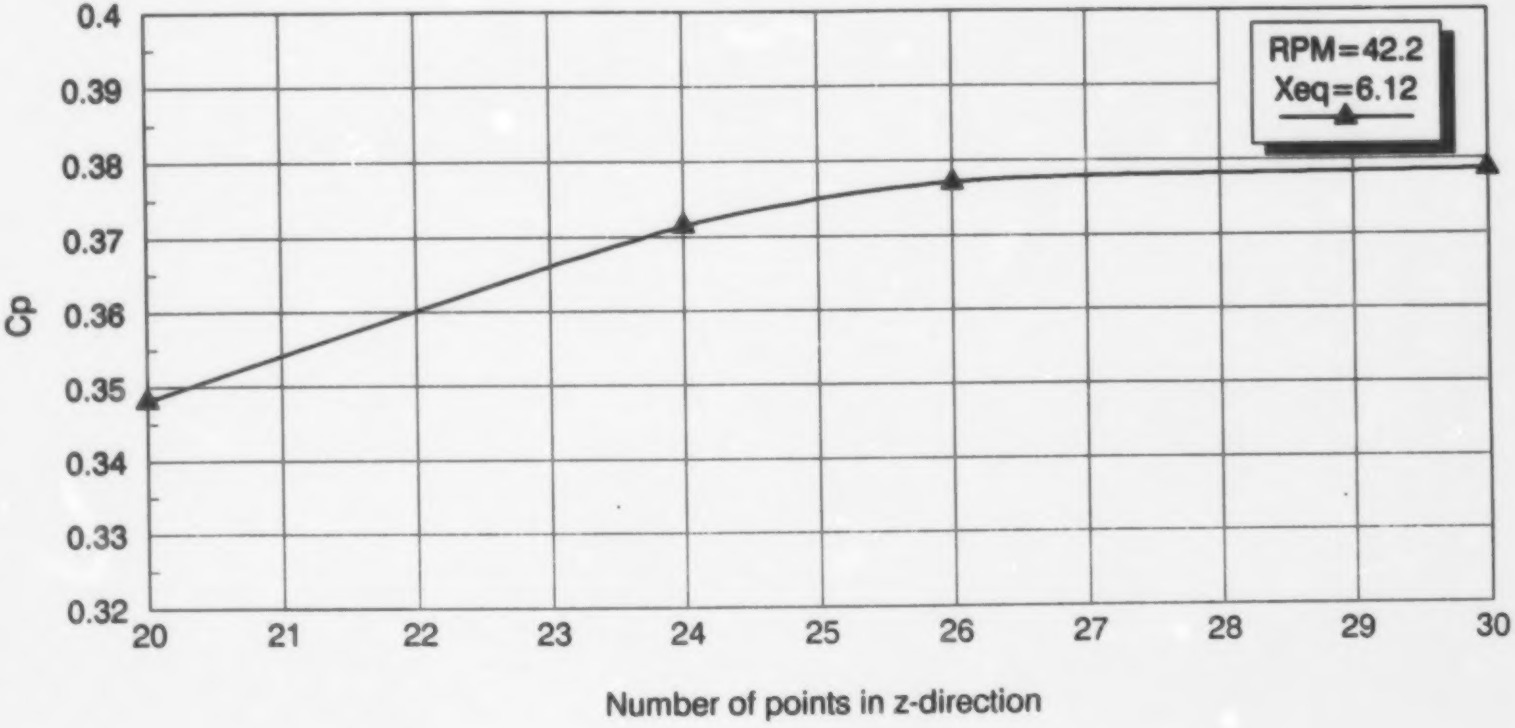

Fig. 6 Effect of grid points in z-direction on Cp

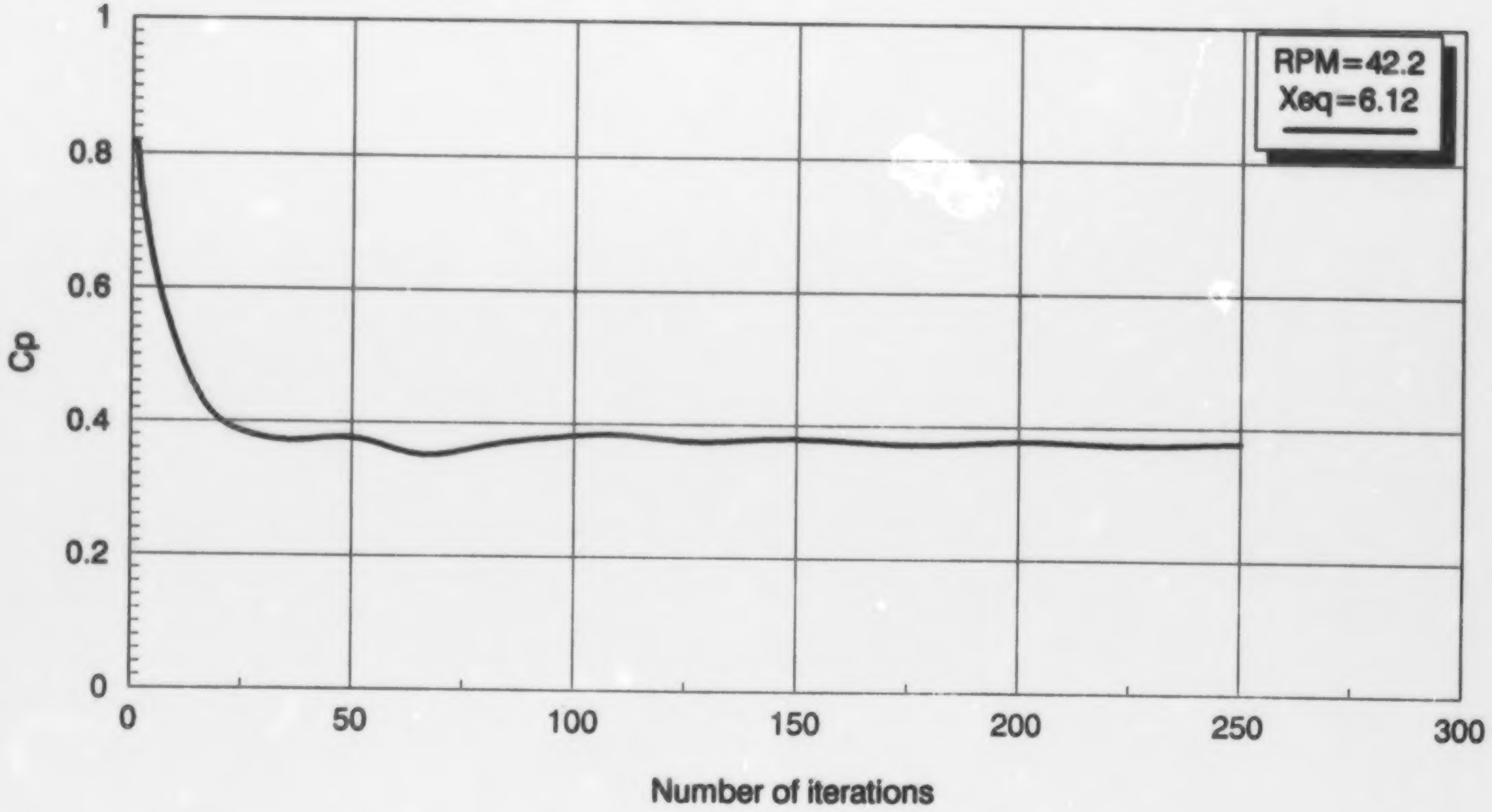

Fig. 7 Convergence history

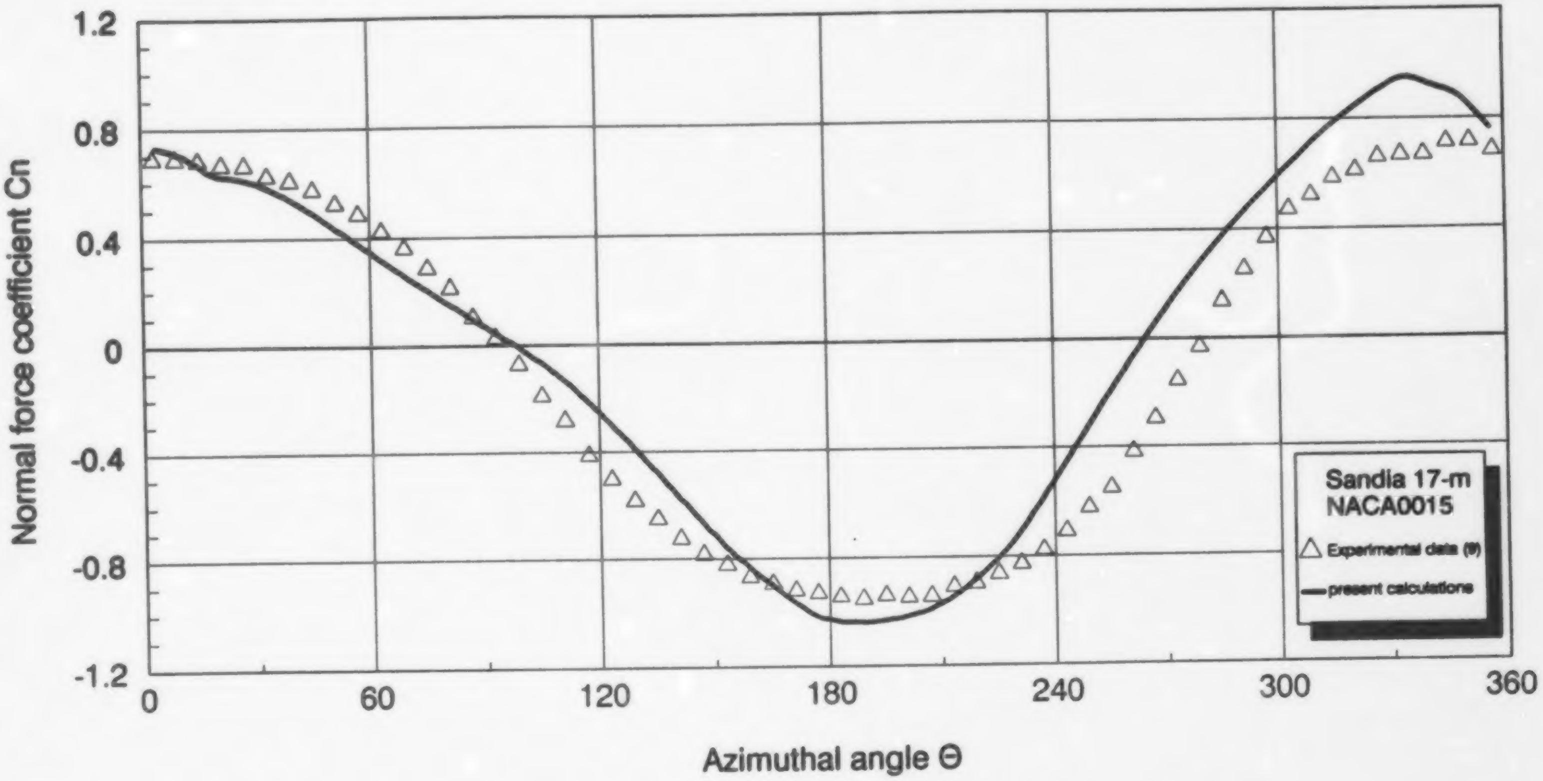

Fig. 8 Normal force coefficient vs azimuth at RPM=38.7 and Xeq=4.60

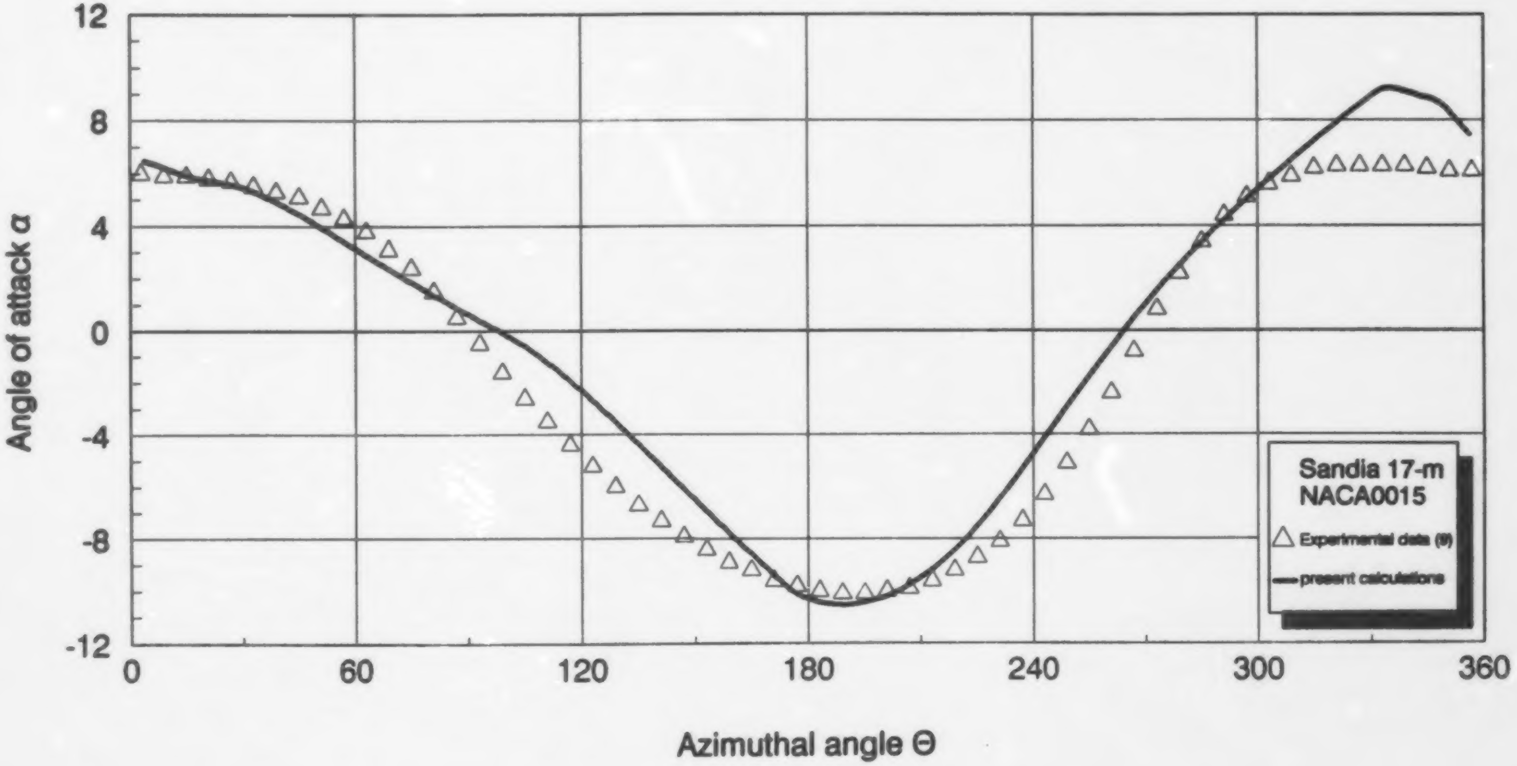

Fig.9 Angle of attack vs azimuth at RPM=38.7 and Xeq=4.60

Expertise on blade cracks on the Kuujjuaq wind turbine

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VPR, IREQ, Hydro-Québec

Abstract

The wind turbine installed in KUUJJUAQ, a community located far north in Québec, is a 65 kW machine operating with 7,5 meter blades. After nearly 15 000 hours of operations, severe cracks have been detected on one blade.

Expertise have been made on the damaged blade and a new set of blades installed. Results of expertise and problems encountered are described in this report.

Background

The wind turbine installed in Kuujjuaq, a northern remote community located in Ungava bay, is a 65 kW machine manufactured by a Danish company (BONUS). Original blades, supplied by Aerostar, are 7,5 meters long.

Erected in 1986, the installation has been upgraded following a sequence of problems encountered during the demonstration phase (extremely cold weather, capacitor explosion, relocalisation of control panel, etc). The machine presented an availability factor of more than 97% during 1990.

One of the problems we have consistently observed was the overproduction of the machine. As a matter of a fact, data acquisition made for checking the performance curve showed power reaching 80 to 90 kW (5 minutes averages, power not corrected for air density) even though the pitch of the blades was set to the specifications of the manufacturer. If these power measurements are correct, this overproduction may have been a contributing factor in reducing the fatigue life of the blade. Discussions are still going as to the measurement accuracy for correlating power to wind speed. Figure 1 shows a plot of the data collected.

By the end of 1990, the machine had produced 260 000 kWh over 14 500 hours of operation, which represents an average of 17,8 kW when it is producing. The machine has run without any maintenance for almost one year, before a crew went on the site for an annual service visit. During this visit, severe cracks have been detected on one of the blades. Machine has then been stopped and corrective actions were undertaken.

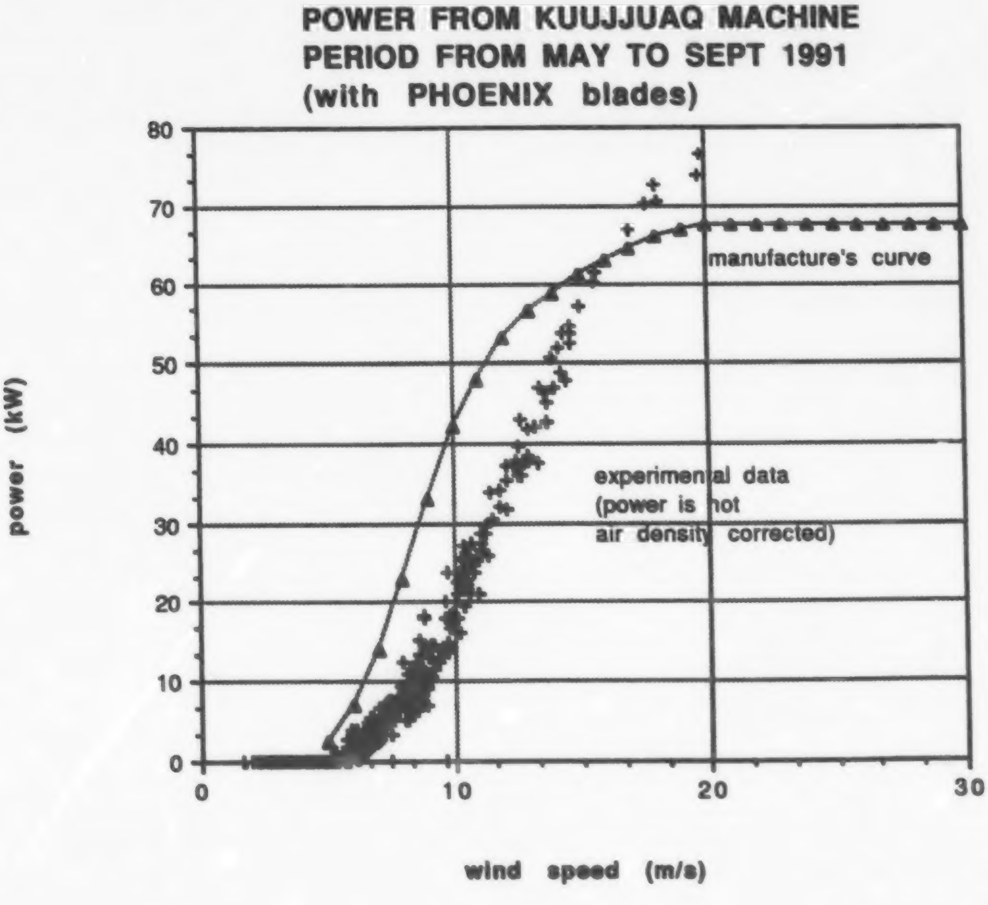


Figure 1

Preliminary observations of the cracks

Three cracks have been detected on one of the blades at approximately 1,50 meter from the blade root: the first one, 5 cm long spanwise, is located on the leading edge. The two others are transversal to this longitudinal crack. They are more than 15 cm long each, reaching the longitudinal one and separated by 1,5 cm as shown on Figure 2 in Annex 1.

On the leading edge, intrados face, surfaces on each side of the cracks are offset by a few millimeters.

Corrective action scenarios restarting the machine

Following discussions with the supplier of the wind turbine, it appeared that we were not sure to be able to fix the blade successfully as the cracks were severe. Then we examine the cost of different scenarios.

The first scenario considered was to repair the damaged blade and put it back on the wind turbine. To do so, we needed staff from BONUS, Denmark, from IREQ and from local community. At the time of the inspection visit, the average outside temperature at Kuujjuaq were around minus 20°C. So, repairing the blade implies removing it from the wind turbine, bringing it into a heated building and wait for temperature stabilization before applying polyester resin. After the cured time, the blade could then be reinstalled on the machine and readjusted. Costs for this repair were evaluated at 24k$.

Fixing the blade this way would not have tell much about status, neither would we have hadany explanations on the origin of the cracks and on the probability of occurrence of other cracks in a nearby future. Also, if the repair of the blade could not be carried out, we were to be left with 24k$ less and a two blades machine.

The second scenario was to discard the old set of blade, and install a totally new set for the wind turbine. To do so, we also needed staff from BONUS, Denmark, from IREQ and from local community. Costs were estimated at 53k$ and one more time, we were not anymore informed on the cracks origin.

The third scenario was to put a new set of blades and repair, if possible, the damaged blade. This way, we were in possession of a spare set on site. Costs were estimated at 67k$ and again, we were not anymore informed on the cracks origin.

A fourth scenario was finally choosen: put a new set of blades, initiate an analysis of the damaged blade and repair it, if possible. This scenario appeared to be the most interesting: we would have new blades on the machine, a spare set, and an expertise on the cracks so that we can take actions trying to prevent it in the future. Costs were estimated at 88k$.

These costs are high but we have to remember the machine localisation, Kuujjuaq, which is 1000 kms from Montréal and costly to reach. As an example, a new set of blades is costing 13 200 CDN$. Bringing them from Minnesota to Montréal, by truck, adds an extra cost of 2 500 CAN$. Kuujjuaq cannot be reached by road: so we had to rent an airplane which costs 17 000 CAN$. Arrived at Kuujjuaq, blades are then costing 32 700 CDN$. The repair took 10 days and involved about 35 man-days.
The financing of the repair was partly covered by a special grant from EMR Canada.

Replacement with new blades and problems encountered

New blades have been ordered from BONUS who subcontracted to PHOENIX INDUSTRIES, from Minnesota, USA. We had to carry them from Crookston to Kuujjuaq in two steps: first to Montréal by truck and then to Kuujjuaq by plane.

When we received the blades in Montréal, they were crated in such a way they had to be manipulated with special care. We had to modify these crates to meet airplane transportation requirements and escort them up to final destination to be sure they would not be damaged anymore (two of them had been rubbing on the floor when downloaded from the truck, scratching leadind edge of tips). Blades have been stored in a safe place at Kuujjuaq airport for a week, waiting for the crew to install them on the machine.

When time arrived to bring the blades to the wind turbine site, we observed two blades showing trailing edges separation on over 80 cm. The blades are made of two shells, intrados and extrados, which are glued together (polyester) along their leading and trailing edges for final assembly. This vital process involves surface preparation of material of the shells, adequate glue preparation and application and of course, a large contact surface. In the area where edges were separated, the actual contact surface where glue had been applied was approximately 2 to 5 millimeters wide instead of the 50 to 70 millimeters recommended.

Arrangements have been made with the blade supplier so that they send a man to repair it, installing new coats of fiberglass over these sections of trailing edges. At the same time, damaged blade tips were repaired.

The next problem happened when we wanted to align the blade flanges onto the wind turbine hub for the correct pitch. Usually, we were using a template we fitted on the blade and a theodolite for aligning it the specified pitch angle. On these new blades, the template was not fitting anymore, the shape of the blade being slightly different. We then adjusted the blades to the minimum possible pitch since we didn't want anymore an overproducing machine.

Collecting data over the next five months, we found out that the machine was still overproducing. Trying to reduce the pitch, we noted that these adjustments were impossible because of misalignment of bolt holes or different neutral axis in these blades compared to the previous set. The only way we found to reduce output power from the machine was to apply a rough coating, mixing sand and paint, over 25 cm on last section of leading edges. Data collected over next month will tell us the effects of this custom modification.

Visual Inspection of the inside of the damaged blade

A visual inpection of the internal surfaces of the damaged blade is possible through a hole at the blade root, on flange side. It shows interesting points: the blade neck (section between the flange and the fully developed blade shape) is made of coatings of fiberglass, the same way the whole blade should be, but in addition, its internal face is covered with a compound, probably the same used for flange, which is nearly one inch (2 to 3 cm) thick.

At the end of this "heavy" neck, looking towards the tip of the blade, there is an area, approximately 4 inches (10 cm) long in the blade axis direction, where the thickness of fiberglass is thinner than the rest of the blade. It looks like if a few coats of fibers had been layed out from the blade tip and were too short to reach the neck. The result is the creation of an area which causes a steep change in the moment of inertia and the load transfer characteristics of the blade. The transversal cracks have occured in this weaker area.

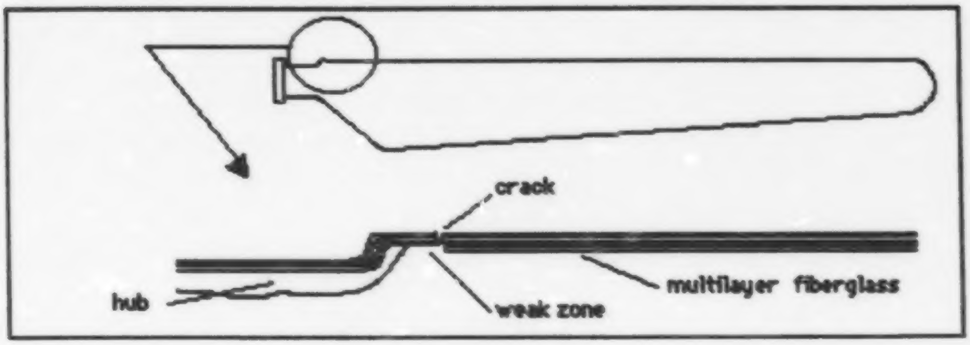


figure 2

So, we can say that the longitudinal crack has been initiated due to inadequate assembly, and transversal cracks were developped by cyclic strains in an area presenting weaker load transfer characteristics. After repairing the blade, we've added some more coats of fiberglass over the weaker zone, covering the neck and intrados/extrados surfaces of the blade with multiple layers, each coat being smaller than the previous one, to re-establish a more gradual distribution of moment of inertia .

Expertise on damaged blade

Morphologic analysis of blade cracks area has been made. Results are included in annex 1. In short, this analysis shows that the first crack to appear was the longitudinal. It has been initiated due to the poor cohesion and adhesion between the two shells of the blade glued together at leading edge. This default traces back to fabrication and can be associated to different factors: improper surface preparation of fibers, inadequate chemical treatment before impregnation, too short curing time and/or polyester application procedure, etc. Care taken during each of the different steps of the fabrication process are critical in the overall quality of the final blade.

Conclusion

One of the possible cause of the blade failure is due to the way blades are assembled: making them from outside to the inside. The process starts with the application of a gelcoat in the matrix of the blade, creating the blade finish. The last process of shells preparation concerns the internal surface structure. It seems that the method of fabrication does not insure a consistent outcome in that part of the process. The problems observed with the new blades in Kuujjuaq point also to potential improvements of the techniques and procedures used during assembly of the shells.

Unfortunately, the predominant conclusions that emerges from this particular experience and the materials analysis of the damaged blade raise numerous questions about quality control during blade construction.

Analyse morphologique des fissures sur une des pales de l'éolienne de Kuujjuaq

Phuc Nguyên-Duy, Sophie Boisvert, Claude Lanouette
Mécanique de rupture et Intégrité structurale
Technologie des matériaux
Vice-présidence Recherche

I. Introduction

Lors de l'inspection périodique, le personnel d'Hydro-Québec a détecté la présence de fissures relativement importantes sur une des pales de l'éolienne de Kuujjuaq. Le but de cette étude est de déterminer la nature de ces fissures, la séquence et les causes de leur création.

Les photographies montrées à la figure 1 permettent de localiser ces fissures. Elles sont au nombre de trois dont une longitudinale et deux transversales identifiées A et B se trouvent à environ 1.50m de la base de fixation.

Notons que la pale se compose de fibres de verre dans une matrice de polyester. La pale ainsi formée est ensuite recouverte d'un revêtement de protection contre les intempéries. Dans la région où sont les fissures, la pale est recouverte en plus d'une couche de polyester d'une largeur d'environ 25cm où a pris naissance la fissure longitudinale (voir figure 1.b).

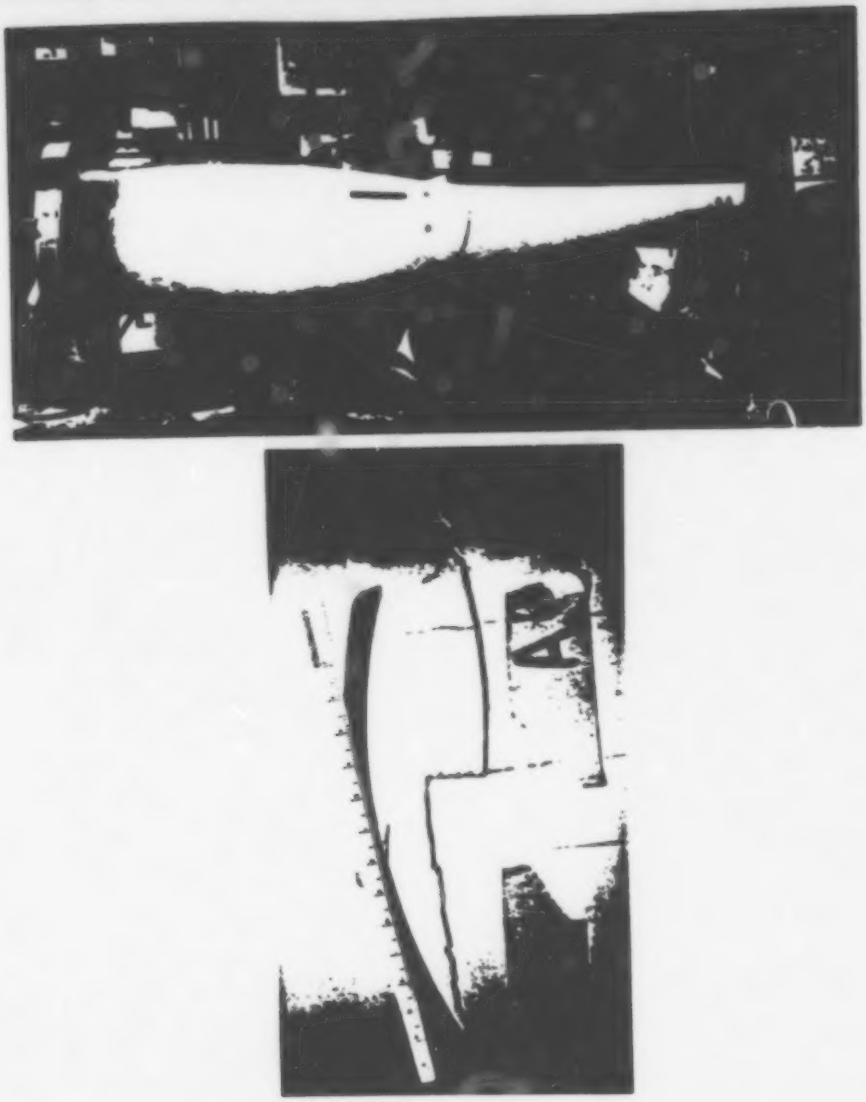


Figure 1: Localisation des fissures sur une des pale de l'éolienne Kuujjuaq

II. Observations macroscopiques et mode de chargement:

Un schéma montré à la figure 2 permet de mieux visualiser les trois fissures. Nous pouvons en déduire que la fissure longitudinale est la première créée. Ainsi, lorsque cette fissure s'est formée, elle a agit comme un concentreur de contraintes et a entraîné la formation des deux autres fissures transversales. De plus, l'ouverture des lèvres des fissures A et B décroit en s'éloignant de la fissure longitudinaie ce qui confirme la séquence de création des fissures proposée.

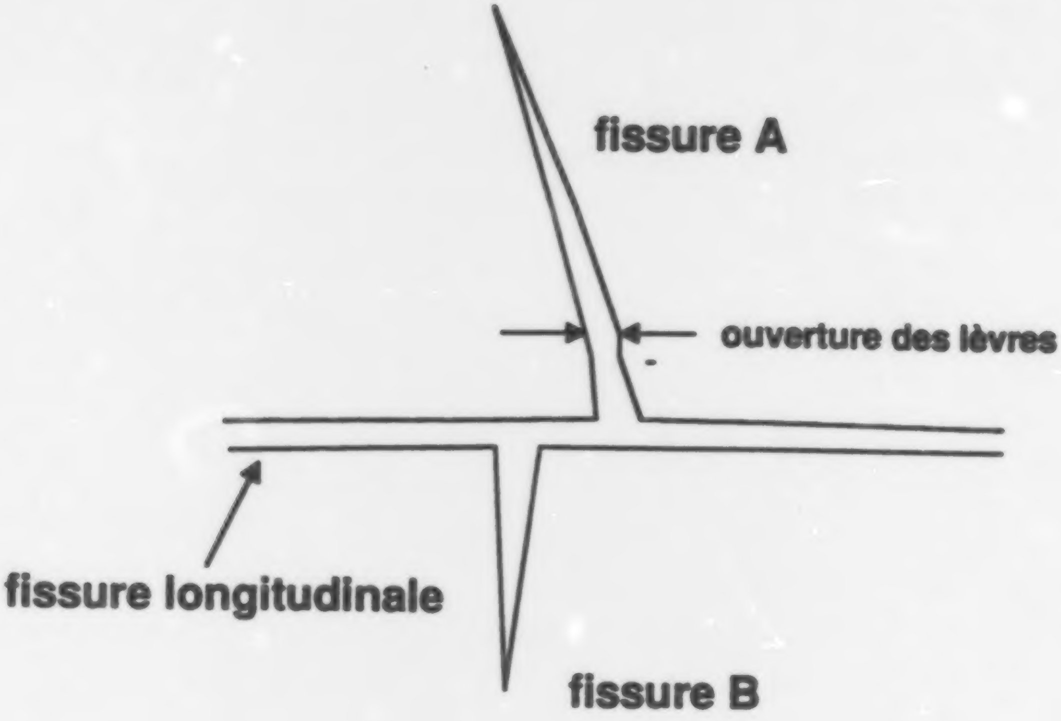


Figure 2: Schéma des trois fissures

Dans une structure exempte de défauts intrinsèques au matériau, ou de fabrication, le système de chargement qui a créé la première fissure longitudinale doit être un système transversal. Ce système de chargement est cependant différent de celui qui a initié les deux fissures transversales A et B. La création de fissures longitudinales par ce système de chargement serait très peu probable. Il est important aussi de mentionner que les deux fissures transversales se propagent presque à la limite du raidisseur qui se trouve à l'intérieur (voir figure 3).

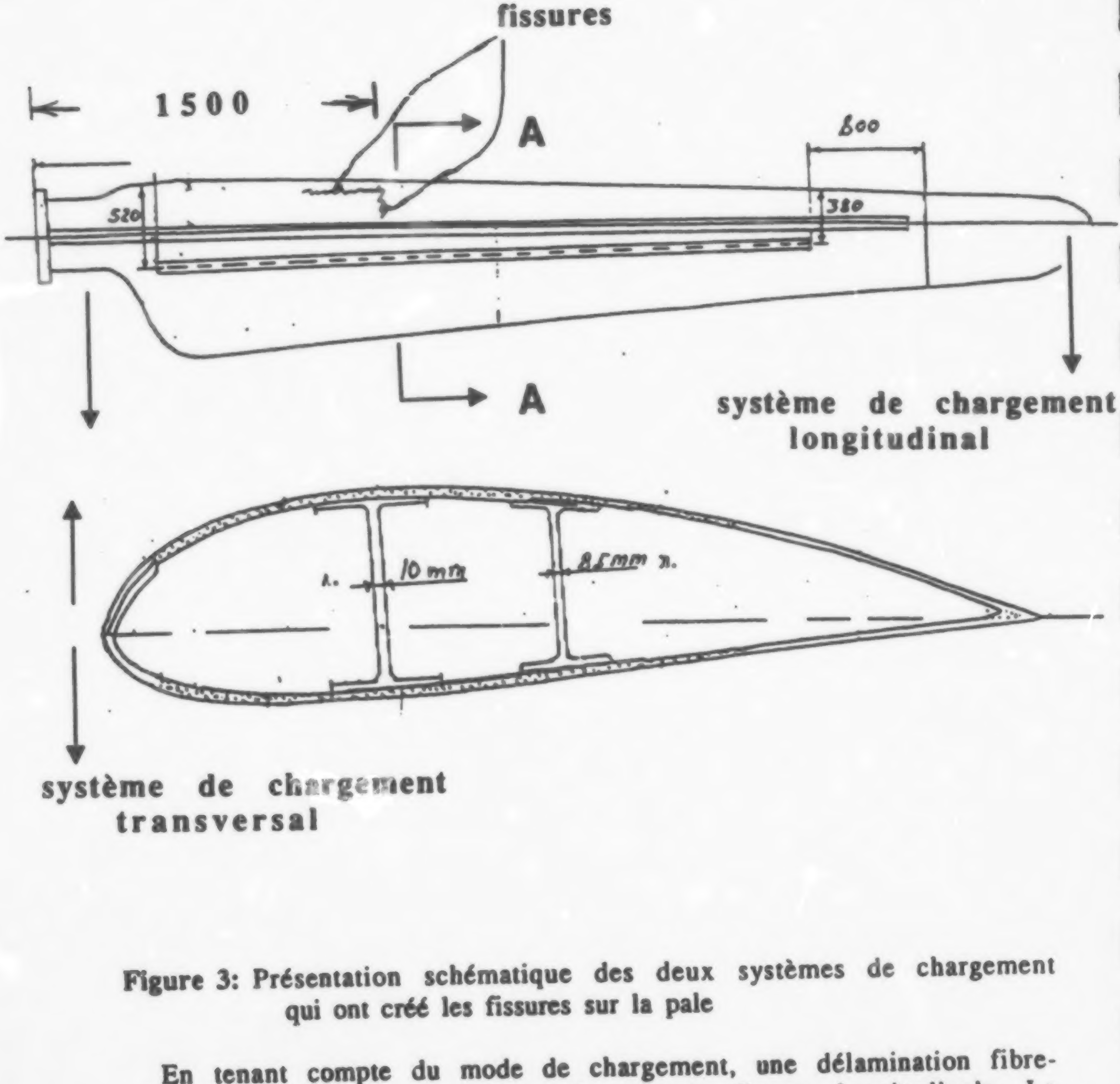

fissures
1500
A
800
520
380
A
système de chargement longitudinal
10 mm
8,5mm
système de chargement transversal

Figure 3: Présentation schématique des deux systèmes de chargement qui ont créé les fissures sur la pale

En tenant compte du mode de chargement, une délamination fibre-matrice serait la cause de la création de la fissure longitudinale. La délamination se produit aux endroits où la force de cohésion fibre-matrice est faible. Ainsi, le mode de chargement pouvant initier une fissure longitudinale n'est pas nécessairement transversal mais aussi longitudinal. La figure 4 illustre schématiquement ce système de chargement .

La faiblesse de cohésion matrice-fibre se produit lors de la fabrication de la pièce et dépend de plusieurs facteurs:

- l'état de surface des fibres;
- le traitement chimique des fibres avant l'imprégnation;
- le dégazage et le temps de prise de la matrice polyester.

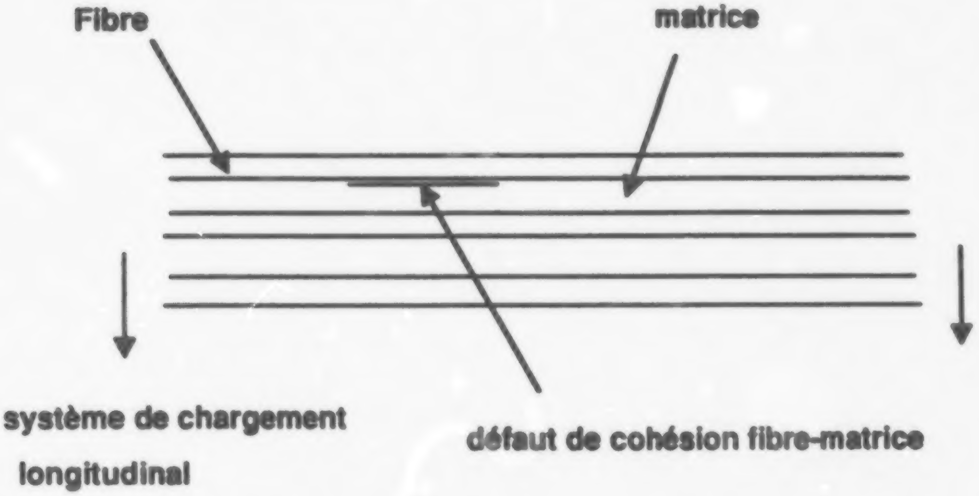

Fibre
matrice
système de chargement longitudinal
défaut de cohésion fibre-matrice

Figure 4: Création de fissures longitudinales par le système de chargement longitudianl en présence de défauts de cohésion fibre-matrice

Lorsqu'il y a une délamination entre les fibres et la matrice, la fissure se propage en mode combiné: la rupture des fibres en cascade; la décohésion matrice-fibre et la rupture de la matrice .

Afin d'observer la morphologie des surfaces de rupture au microscope électronique à balayage , nous avons prélevé aux endroits indiqués sur la photographie de la figure 5 quelques échantillons de surfaces de rupture. Nous avons prélevé peu d'échantillons parce que Hydro-Québec a décidé de réparer la pale fissurée.

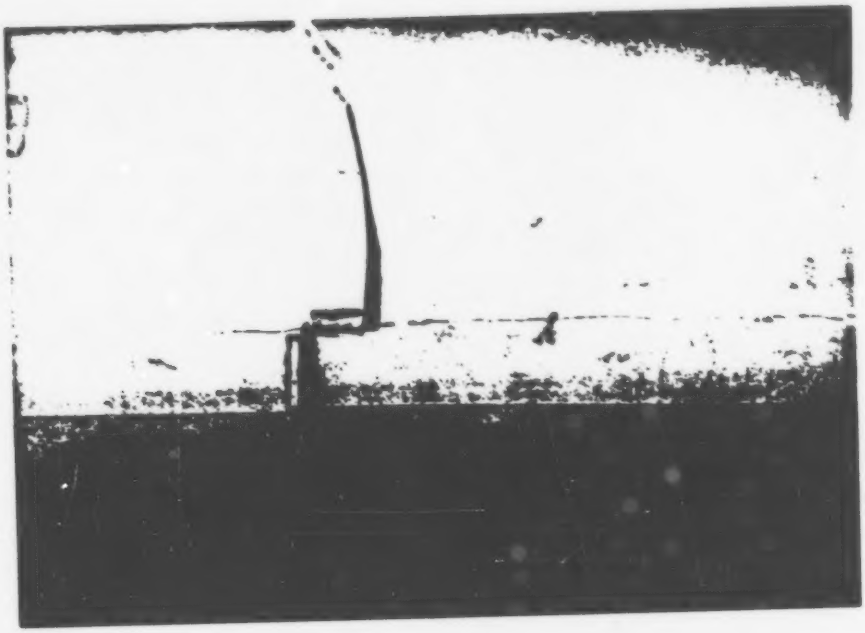


Figure 5: Endroits de prélèvement d'échantillons pour les observations microscopiques

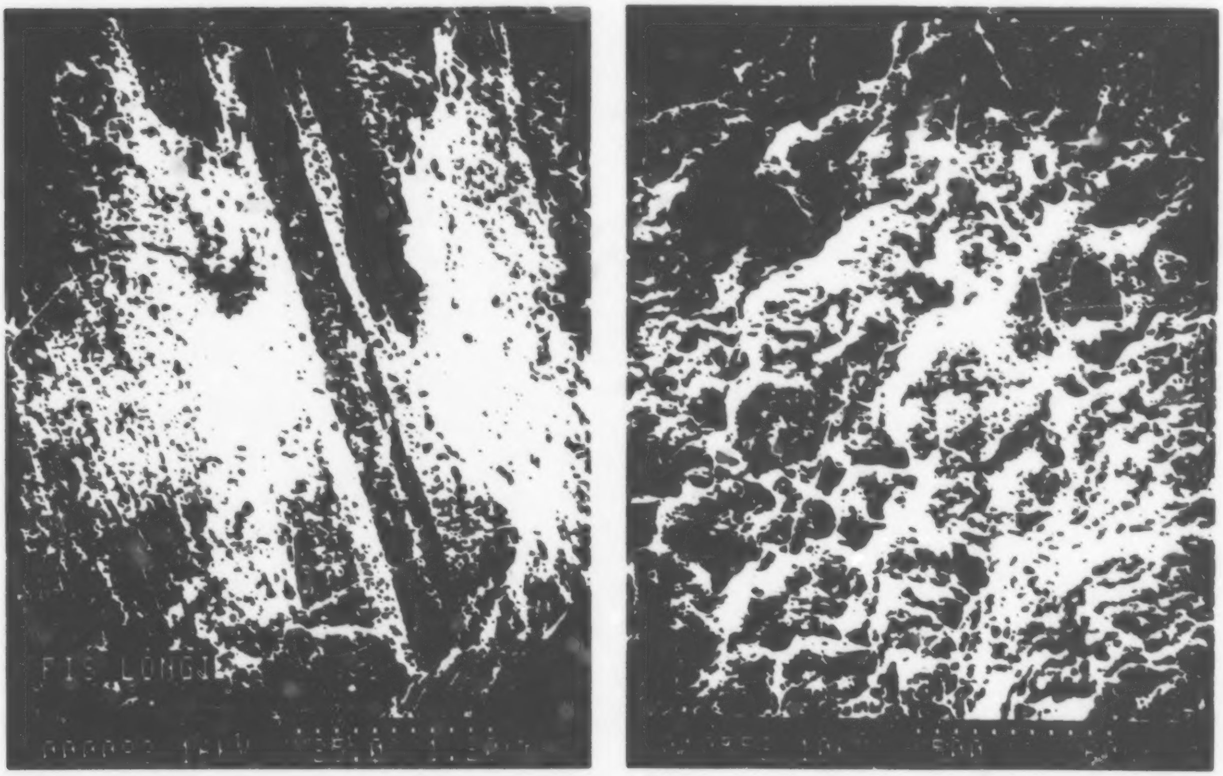
III. Observations de la morphologie des surfaces de rupture au microscope électronique à balayage:

D'abord, il est important de se rappeler que comme dans le cas des composantes métalliques, les modes de ruptures des composantes faites en composite (fibres de verre-polyester) se divisent aussi en deux catégories

- rupture ductile: caractérisée par une morphologie dite "haute-énergie" dont la surface est très accidentée avec les fibres qui ne sont pas au même niveau;

- rupture fragile: caractérisée par une morphologie "basse énergie" dont la surface est plate et lisse. Ce type de rupture se divise en deux sous-groupes:

- la surface de propagation de la fissure constituée du clivage de la matrice et la rupture des fibres perpendiculaire aux fibres;
- la surface de rupture constituée du clivage de la matrice le long des fibres et la décohésion à l'interface fibre-matrice. L'état de l'interface permet de porter un jugement sur la force de cohésion fibre-matrice.



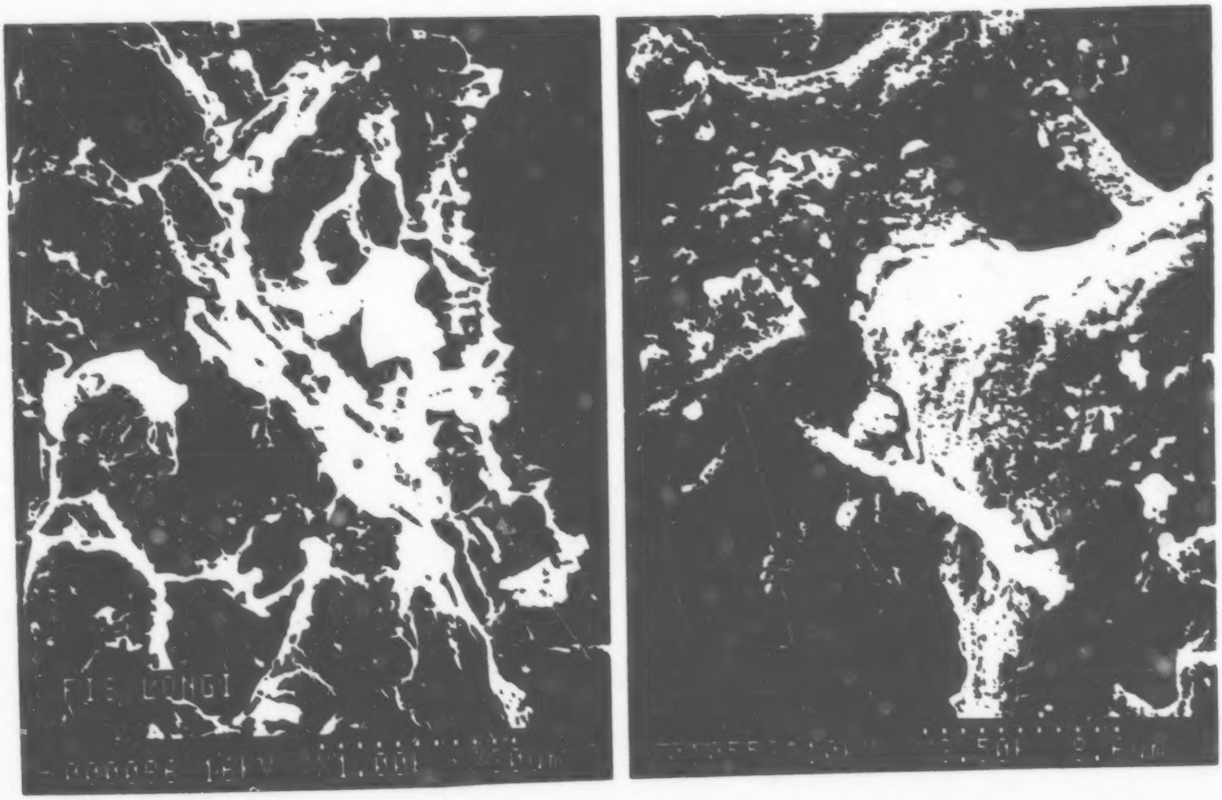
(a) (b)

Figure 6: Surface de rupture de la fissure longitudinale- région près de la surface extérieure.

III.1. Fissure longitudinale:

Les figures 6.a et 6.b montrent la surface de rupture longitudinale . La surface de rupture est relativement plate et lisse avec la présence de fissures secondaires dans la matrice. La surface extérieure se trouve à gauche de la photographie, la couche de polyester ajoutée à la surface (à gauche) est très poreuse et se décolle de son substrat. Ce manque de cohésion entre la couche de polyester et le substrat peut causer l' amorce de fissures.

La figure 7.a indique les zones de clivage de la matrice. À plus fort grossissement, nous pouvons voir l'empreinte des fibres arrachés. Il y a très peu de déformation ce qui indique la cohésion entre fibres et matrice est faible (voir figure 7.b).



(a) (b)

Figure 7: Surface de rupture de la fissure longitudinale- région du milieu de l'épaisseur.

La figure 8 montre la morphologie de la zone de propagation loin de la surface extérieure. Notons avec les lignes caractéristiques de la propagation par fatigue dont la direction est perpendiculaire à ces lignes.

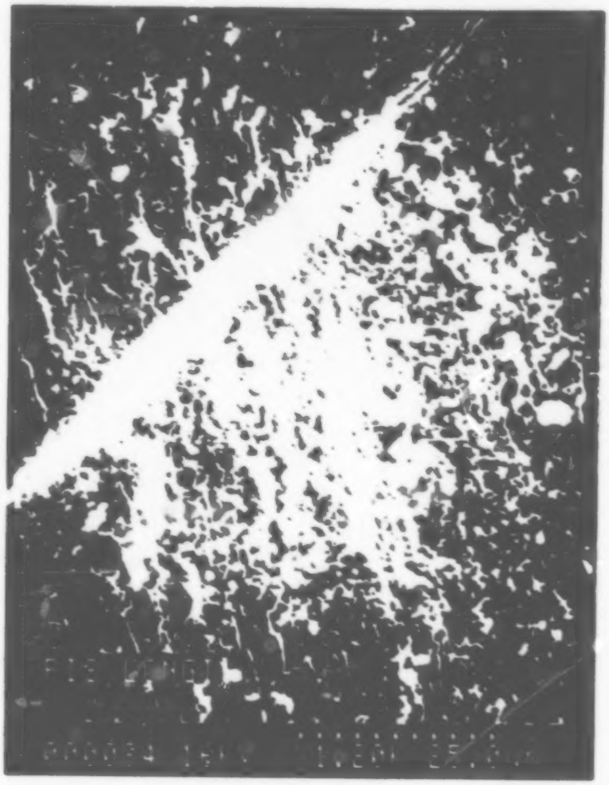


Figure 8: Fissure longitudinale- zone de propagation

La fissure longitudinale a pris naissance dans une région près de la surface probablement à l'interface de la couche polyester et du substrat; elle s'est propagée ensuite vers l'intérieur et le long de l'axe longitudinal. La propagation semble être facile en se basant sur le peu de déformation observée dans la matrice et à l'interface matrice-fibre. De plus, il y a des indications permettant de conclure que la force motrice de la propagation de la fissure est le chargement cyclique.

III.2. Fissure transversale A:

Lorsque la fissure longitudinale est créée, elle agit comme concentreur de contrainte à partir duquel prennent naissance des fissures transversales.

La figure 9 montre à faible grossissement (17X) l'apparence de la surface de rupture de la fissure A:

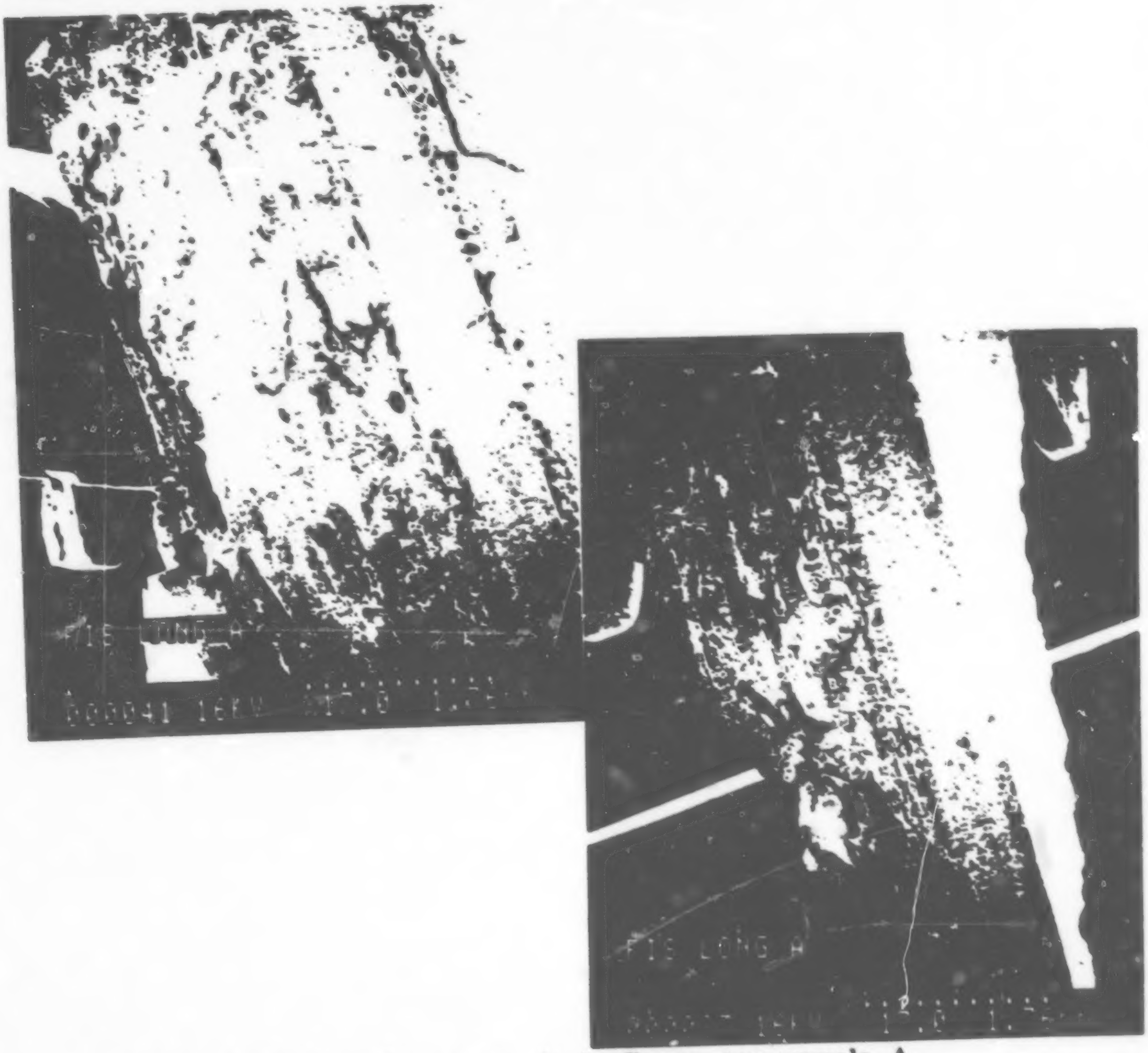
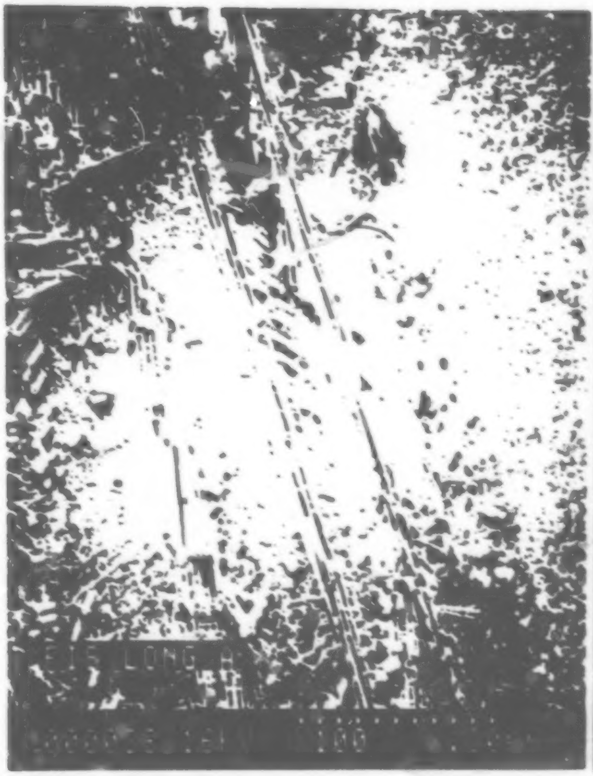


Figure 9: Surface de rupture de la fissure transversale A

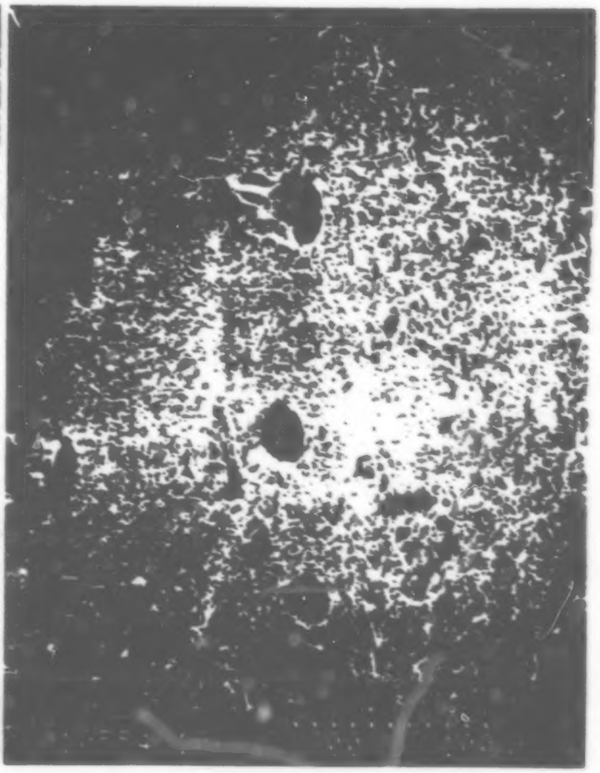
- porosité et fissures secondaires à l'interface de la couche de polyester et du substrat;
- surface de rupture plate et lisse.

Les observations à plus fort grossissement (voir figure 10) ne font que confirmer ces énoncés. Peu de déformation plastique accompagne l'amorçage et la propagation de la fissure particulièrement la matrice autour des fibres ce qui indique manque de cohésion entre fibre-matrice.

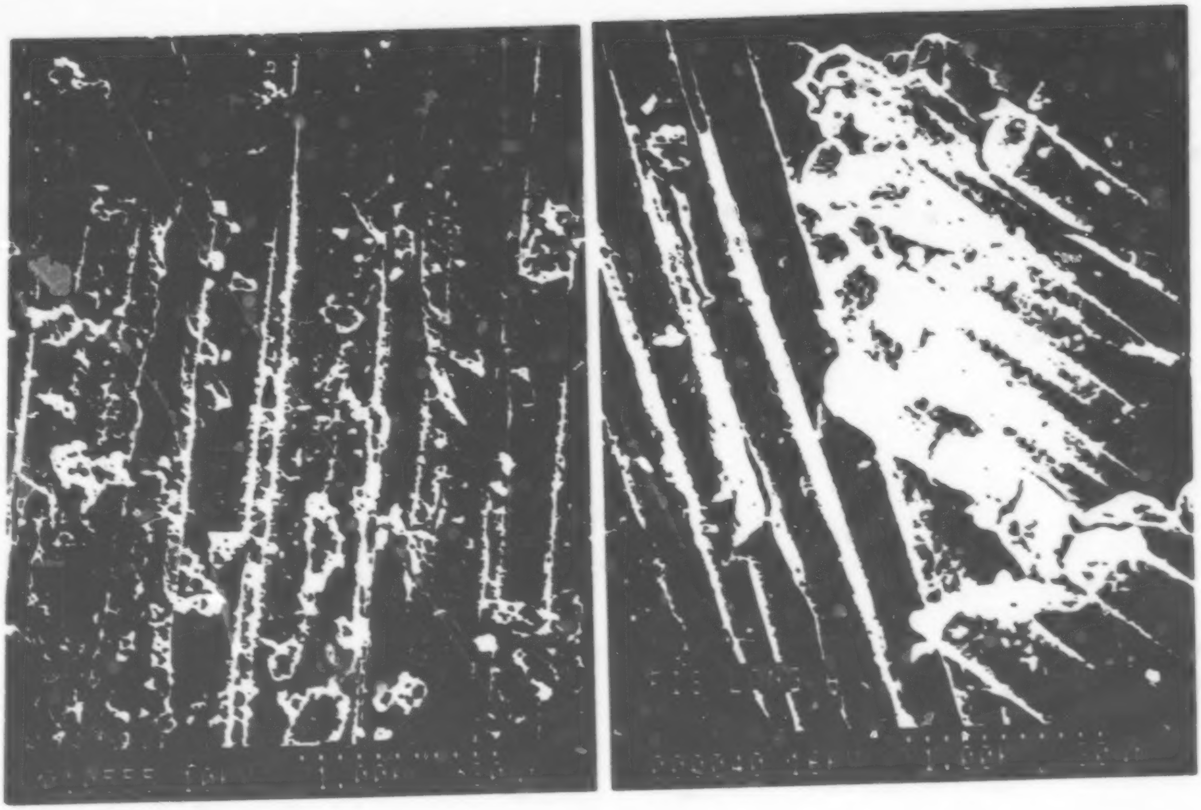
La portion de la surface de rupture montrée à la figure 11 contient des lignes caractéristiques d'une propagation causée par un chargement cyclique, ces lignes sont perpendiculaires à la direction de propagation.



(a)



(b)



(c) (d)

Figure 10: Surface de rupture de la fissure A- peu de déformation à l'interface fibre-matrice

IV. Causes et scénario de la création des fissures:

À cause d'un manque de cohésion (porosité, faible cohésion matrice-fibre), une fissure longitudinale a pris origine à approximativement 1.5m de la base de fixation dans la région de jonction des deux moitiée de la pale. Cette fissure s'est propagée par fatigue vers l'intérieur et le long de l'axe longitudinal. À deux endroits sur cette fissure longitudinale, sollicités par un chargement cyclique de flexion, deux fissures transverales se sont amorcées et propagées.

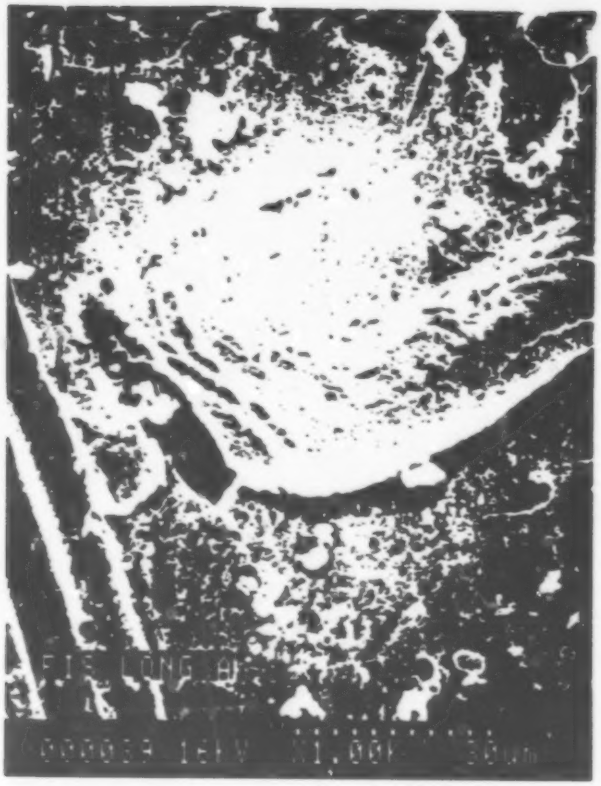

FIS LONG A
000039 15KV X1,00K 30µm

Figure 11: Lignes caractéristiques de la propagation par fatigue sur la surface de rupture transversale A.

WIND TUNNEL TESTS ON A WIND TURBINE BLADE SECTION WITH SIMULATED GLAZE AND RIME ICING

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ABSTRACT

Wind tunnel testing on an airfoil used for the blades of a Carter-23 wind turbine, was done in a low speed wind tunnel under various simulated glaze and rime icing conditions. Data of lift, drag and pitch moment coefficients for both the clean and iced blade were collected. These data were input into a computer program, in which lifting-line theory was used, to compute the performance degradation of a Carter-23 wind turbine by icing.

1. INTRODUCTION

Research has shown that ice accretion on wind turbine blades results in significant aerodynamic penalties leading to loss of power generated [1, 2, 3]. To make accurate predictions of this power loss, it is necessary to have access to the aerodynamic characteristics of wind turbine blade sections over a wide range of angle of attack. Tests were done in a low speed wind tunnel on a NASA LS(1)-0417 wing section under conditions of simulated icing. Rime and glaze ice profiles were simulated by using wood sections attached to the leading edge of the airfoil. These simulated ice profiles were made in the model shop at the Faculty of Engineering and Applied Science, Memorial University of Newfoundland. The airfoil, which had a span of 0.8 m and a chord of 0.2 m, was computer numerically machined from aluminium alloy in the Department of Mechanical Engineering, University of Victoria.

The ice shapes modelled were documented from tests with a model wind turbine in a cold room [2]; from tests in an icing wind tunnel (Lewis Research Centre, NASA) [4]; and from tests done for the Boeing company [5]. For the glaze ice profiles, results show a sharp decrease in lift coefficients and an increase in drag coefficients in the region up to and over stall. The rime ice profile tested showed only a marginal degradation in aerodynamic performance of the section. Glaze ice accretion leads to significant reduction in power produced by a wind turbine.

An estimation was made of the power reductions expected from a wind turbine operating in areas of high icing.

2. EXPERIMENTAL FACILITIES

The airfoil tests were performed in a low speed wind tunnel located at Memorial University of Newfoundland. Figure 1 shows a layout of the wind tunnel. This wind tunnel is about 10 meters long and has two working sections; it has a cross section of 1 × 1m. Section one is a boundary layer testing section and section two, which was used for the airfoil tests, is upstream of section one and provides space where non-boundary layer tests can be conducted. The maximum wind speed that could be provided by the wind tunnel at the section two was about 14.5 m/sec. The turbulence was about 1% at points located 0.07 m away from the tunnel walls and much lower at points further away from the walls [6]. The turbulence is defined here as standard deviation divided by the mean wind speed.

Wind speed in the tunnel working section was measured by using a Disa hot-wire constant temperature anemometer (CTA) (Disa-55M01) with a P-11 hot-wire sensor and Dantec-Acqwire data acquisition software. A two degree of freedom traverse was designed to support the hot-wire probe so that the sensor could be positioned at any point across the tunnel working section.

To achieve measurements of aerodynamic forces exerted by the airstream on the airfoil, an Aerolab Pyramidal strain gauged balance system was used to support the model inside the wind tunnel. Figure 2 shows this device. Six force components could be detected via six strain gauge bridges; each unit was mechanically independent. The angle of attack of the airfoil could be adjusted over a range of ±25 degree and its angle of yaw over 360 degrees. A mounting adaptor was machined to extend this range of angle of attack to that from -6° to 90° to fulfil a full range of airfoil tests.

A multi-channel strain-gauge amplifier was used to amplify the signals from the strain gauges on the dynamometer, which were then sent to a micro computer through a Keighley S575 analogue-digital system. Figure 3 shows the instrumentation for the wind tunnel tests.

3. TEST PROCEDURE

The airfoil tested was a NASA LS(1)-0417 wing section with a 0.2 m chord length, 0.8 m wing span and hence an aspect ratio of 4. This model was made from aluminium alloy (6061-T6) and it was manufactured on a CNC machine at the University of Victoria. The NASA LS(1)-0417 wing section is similar to the blade sections used for the Carter-23 wind turbine. The simulated ice shapes, which were for typical rime and glaze ice conditions, were attached to the leading edge of the airfoil and were fixed by using double-sided sticky tape so that they could be replaced easily for each test. The gaps between the simulated ice accretions and the airfoil itself were sealed by plasticine. Figures 4, 5 and 6 show the simulated glaze1 (G1), glaze2 (G2) and rime1 (R1) ice accretions mounted on the leading edge of the airfoil. The G1 ice shape was documented from tests with a model wind turbine in a cold room [2] that lasted 5 minutes under the conditions of room temperature of -5°C, wind speed of 4 m/sec, liquid water content of the air of 1.6 g/m^3 and size of the water droplets of 0.6 mm in diameter. G2 was from tests in an icing wind tunnel at the Lewis Research Centre, NASA [4], under conditions of ambient temperature of -7°C, wind speed of 57 m/sec, liquid water content of 2.1 g/m^3 and diameter of the water droplets of 0.02 mm. R1 was from tests done for the Boeing company [5].

The airfoil was mounted on a mounting plate located on the top of the dynamometer support bar. After installation of the airfoil, the whole force measuring system was balanced; all the signal components of force and moment from the strain gauge amplifiers were set to zero before every test. The wind speed inside the wind tunnel was set to 6 m/sec which gave a Reynolds number of 0.8×10^5 for the section; this was determined by the capacity limitation of the dynamometer.

Airfoil tests then proceeded over a range of angles of attack from -6° to 90° at 2° increments. At each step, sufficient time was allowed to overcome flow transition effects around the airfoil and to stabilize the flow field after adjustment of the angle of attack. The micro computer recorded the data from each strain gauge amplifier channel and averaged the forces and moment exerted on the body of the airfoil over a 40 seconds time duration.

4. TEST RESULTS AND DATA CORRECTION

Four tests were conducted: for the clean airfoil; the airfoil with simulated glaze ice G1 and G2; and for the airfoil with rime R1 ice accretions on the leading edge. Figures 7 to 12 show results of lift, drag coefficients over angles of attack from -6° to 90° for these tests.

The object of the wind tunnel tests was to obtain the airfoil performance in open air conditions. As a result of distortion of the flow pattern due to the limited cross section of the tunnel, energy dissipation in the wake and because the flow field inside the wind tunnel was not exactly two dimensional, the raw test data had to be corrected. For a closed wind tunnel, if the working section has straight rigid boundaries, continuity of mass flow in the tunnel requires that the axial velocity in the vicinity of the model must exceed the value well upstream, the so called tunnel velocity U_T. This gives an expression in terms of a blockage factor ϵ,

$$U_F = U_T(1+\epsilon)$$

where the wind speed U_F is taken to be the speed in the tunnel at the position of the model and ϵ can be expressed as

$$\epsilon=\epsilon_s+\epsilon_w$$

where ϵ_s is a solid blockage factor and ϵ_w is a wake blockage factor. The solid blockage factor ϵ_s in two dimensional flow was determined by Lock [7], to be

$$\epsilon_s=\frac{\pi^2\lambda}{12}\left(1+\frac{3\pi^2a^2}{4h^2}\right)^2\left(\frac{t}{h}\right)^2$$

where h is the tunnel cross section height; t is the maximum thickness of the airfoil; a is distance from the location of the airfoil to the centre line of the wind tunnel cross section; and λ is a body factor that depends on the geometry of the airfoil. The body factor is increased by an amount of $K_1\alpha^2$ in which K_1 is a function of t/c and α is the angle of attack. A method to obtain both λ and K_1 was presented by Pankhurst & Holder [7]. The wake blockage factor was taken as [7]

$$\epsilon_w=\eta\frac{t}{h}$$

which is strictly for a wing completely spanning a closed tunnel, where η is an empirical factor described by Pankhurst & Holder [7].

The apparent force coefficient C_{FT} was expressed as a corrected value $(C_F)_F$ corresponding to the value in an open airstream

$$(C_F)_F=\frac{C_{FT}}{(1+\epsilon)^2}$$

As a result of the finite aspect ratio of the airfoil, the flow around the model had a three dimensional component. To allow for this, the drag coefficient, C_D, from the wind tunnel test for finite aspect ratio, A, was converted to an equivalent two dimensional value, C_{DO},

$$C_{DO}=C_D-\frac{1}{\pi A}(1+\delta)C_L^2$$

and the slope of the lift coefficient curve, *a*, for finite aspect ratio was converted to an equivalent two dimensional value a_o, by

$$\frac{1}{a_o}=\frac{1}{a}-\frac{1}{\pi A}(1+\tau)$$

where δ and τ are constants, and C_L is a lift coefficient for finite aspect ratio. Both, a, for a finite aspect ratio of 4 and a_o for two dimensional flow are given by Glauert [8] as 4.04 and 2π respectively. The conversion factor F_L for the lift coefficient from three dimensional to two dimensional flow was obtained as a/a_o.

The original test data were then input into a computer program called COR.FOR and were corrected by using the algorithm above. Figure 7 to 12 show the corrected results only.

Once the airfoil section data were obtained, performance evaluations for a Carter-23 wind turbine, operating in the various atmospheric icing conditions described above, could be made.

5. WIND TURBINE PERFORMANCE DEGRADATION BY ICING

The wind turbine performance calculation was done by using lifting-line theory [9,10] which was adapted for wind turbine use by Bose & Small [11,13] and further adapted by Rong & Bose [1,2] for iced wind turbine use. The method calculates a theoretical lift coefficient for a range of potential angles of attack in the form

$$C_L=\frac{4g\kappa a'}{(1+a')\sqrt{1+\tan^2\beta_i}}$$

where κ is the Goldstein coefficient, a' is the tangential interference factor at the rotor disc, β_i is the aerodynamic pitch angle and g is a gap factor. The set of blade section data for lift and drag coefficients obtained from the wind tunnel tests were read into the program; these were matched with the calculated values of lift coefficient to find the actual operating section angles of attack and the drag coefficient. The method uses the Goldstein factors to correct for the effects of finite blade number and tip losses. The wind turbine's performance of thrust, torque coefficients, efficiency and power ratio were calculated by this program. Only power ratio for the Carter-23 wind turbine is presented here. Power ratio, P_r, is defined as the ratio of the overall power, P, absorbed by the wind turbine to the maximum power that can be absorbed by a wind turbine and is expressed as

$$P_r = \frac{27P}{8\pi R^2 \rho V^3}$$

where ρ is the density of the air, R is the radius of the wind turbine and V is the wind speed. The computational results of power ratio for the Carter-23 wind turbine under clean and various icing conditions are shown in figures 13,14 and 15. The percentage of power reduction in rime icing conditions over tip speed ratio from 0.5 to 12 is 30%. Severe power reduction were encountered in both glaze icing conditions, in which 100% power reduction over tip speed ratio from 0.5 to 12 happened. These imply that glaze icing can destroy wind turbine performance completely.

6. DISCUSSION

Wind tunnel tests showed that a dramatic decrease of lift coefficient and increase of drag coefficient occurred when glaze icing accreted on this airfoil section. Rime icing had less effect on the airfoil performance. The velocity profile and the rate of increase of boundary layer thickness around an airfoil depend on the flow pressure gradient. When the pressure increases in the direction of flow, the boundary layer thickness increases rapidly and the velocity profile is distorted. If this reverse pressure gradient is large enough, then separation will occur followed by a region of reversed flow. Flow separation results in a loss of circulation around the airfoil and hence a reduced lift force as well as an increased pressure drag. Glaze ice formation destroys the streamlined shape of the airfoil so that aerodynamic degradation occurs. As a result of the aerodynamic penalties shown in the wind tunnel tests for the iced airfoil, performance degradation of wind turbine fitted with this section would occur. This would lead to reduce driving torque of a rotor. In actual conditions of wind turbine operation, the flow upstream of a rotor is more turbulent than in the wind tunnel and flow across the wind turbine rotor disk is not uniform due to wind shear effects. As a result, power reduction from a wind turbine by icing may be more severe than that expected theoretically [3].

7. CONCLUSION

Aerodynamic performance of a wind turbine is more sensitive to the shape of ice accretion than the quantity of ice accretion on its blades. Glaze icing on a wind turbine rotor can destroy its aerodynamic performance completely. Similar atmospheric precipitation conditions, but with different ambient temperature, could give significant variation in power output from horizontal axis wind turbines. Freezing events associated with temperature slightly below the freezing point could result in tremendous power losses from a wind turbine. However, heavy icing, no matter what the shape of the ice accretion on, can cause wind turbine rotor to go out of balance and the wind turbine may have to be shut down for safety.

ACKNOWLEDGEMENT:

We thank the following organizations for providing financial support: Energy, Mines and Resources, Canada; Natural Sciences and Engineering Research Council, Canada; Department of Mines and Energy, Government of Newfoundland and Labrador; and Memorial University of Newfoundland. We also thank the technicians in the Thermal lab., Fluids Lab. and machine shop, as well as the members of the Centre for Computer Aided Engineering of our Faculty, for their generous help.

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Figure 1. Wind Tunnel Layout

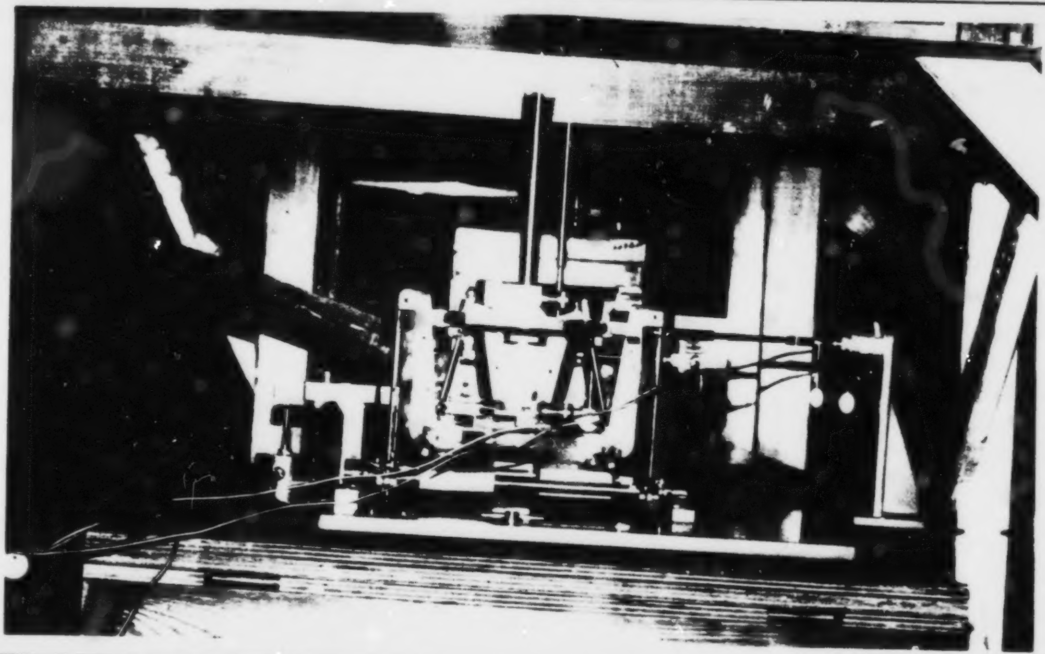


Figure 2. Dynamometer

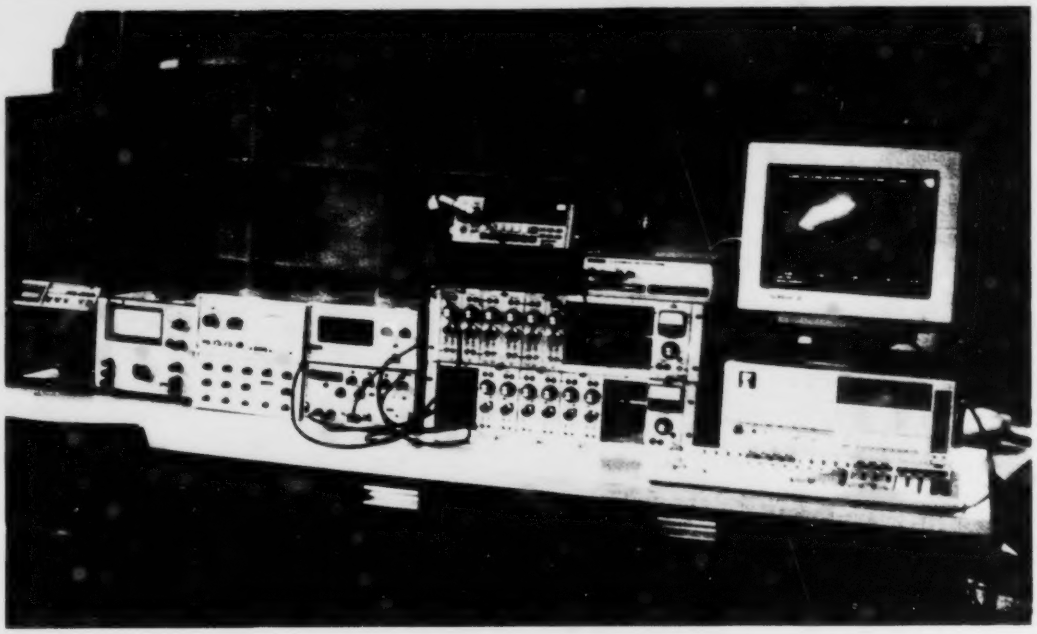


Figure 3. Instrumentation

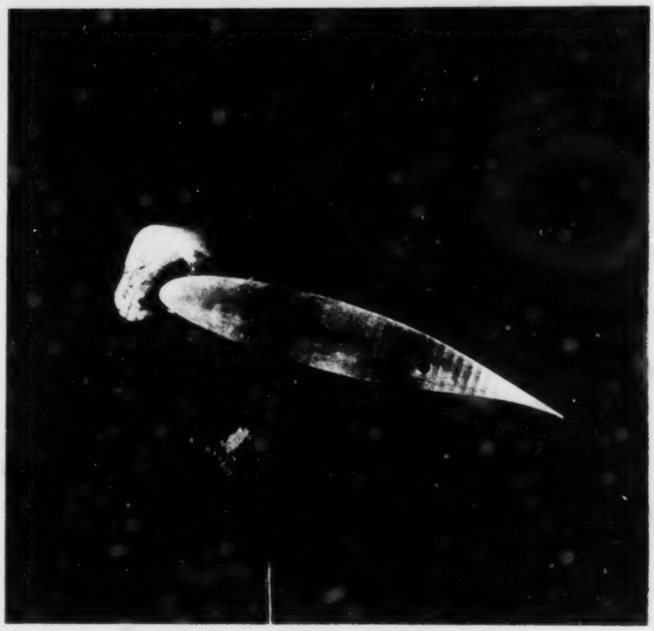


Figure 4. Simulated Glaze1 (G1) Ice Accretion

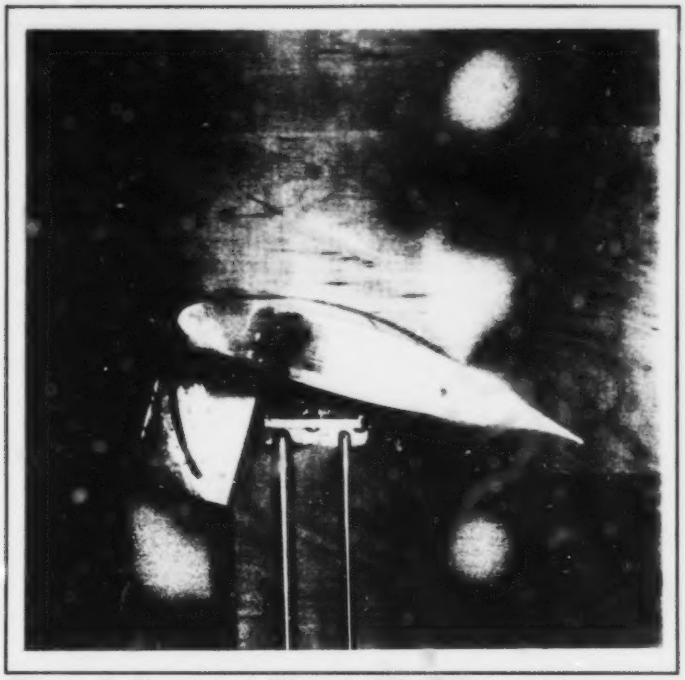


Figure 5. Simulated Glaze2 (G2) Ice Accretion

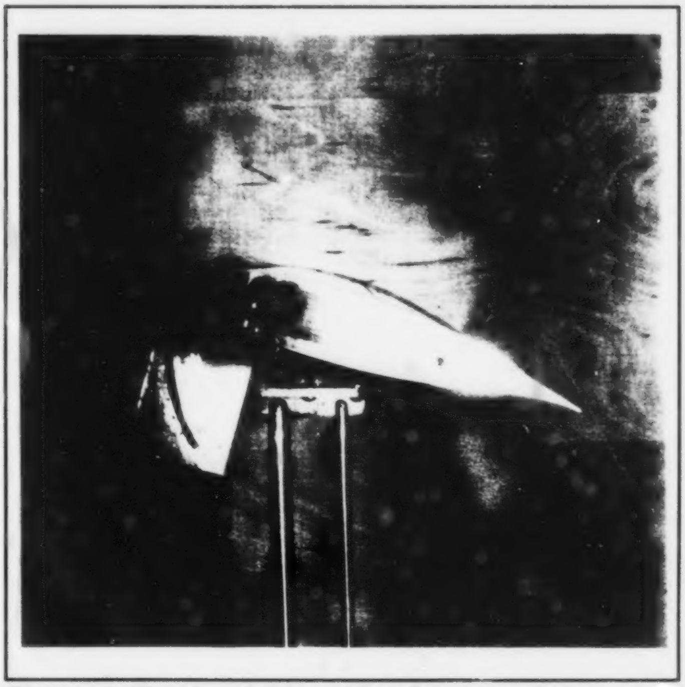


Figure 6. Simulated Rime (R1) Ice Accretion

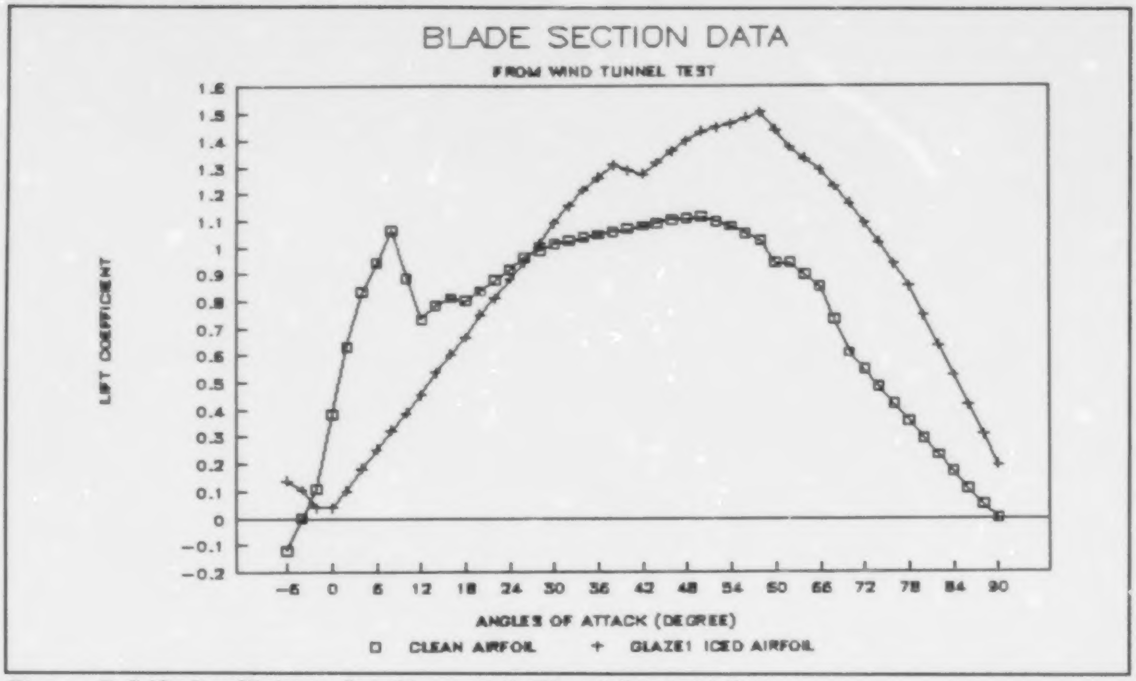


Figure 7. Lift Coefficients for Clean and Glaze1 Iced Airfoil

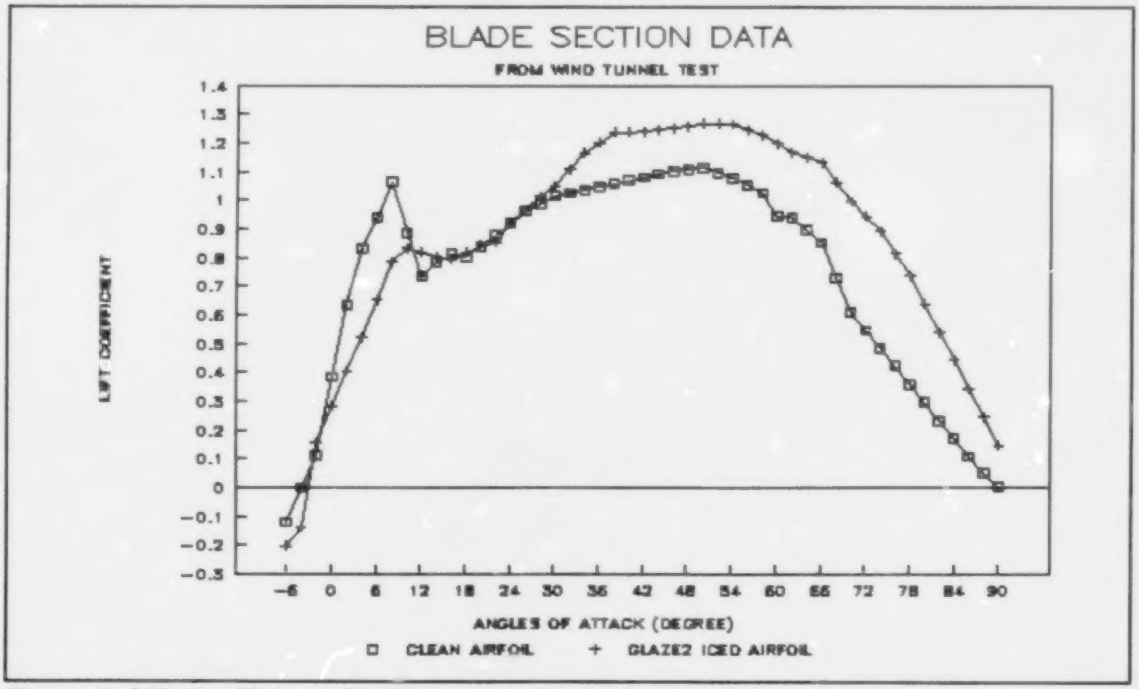


Figure 8. Lift Coefficients for Clean and Glaze2 Iced Airfoil

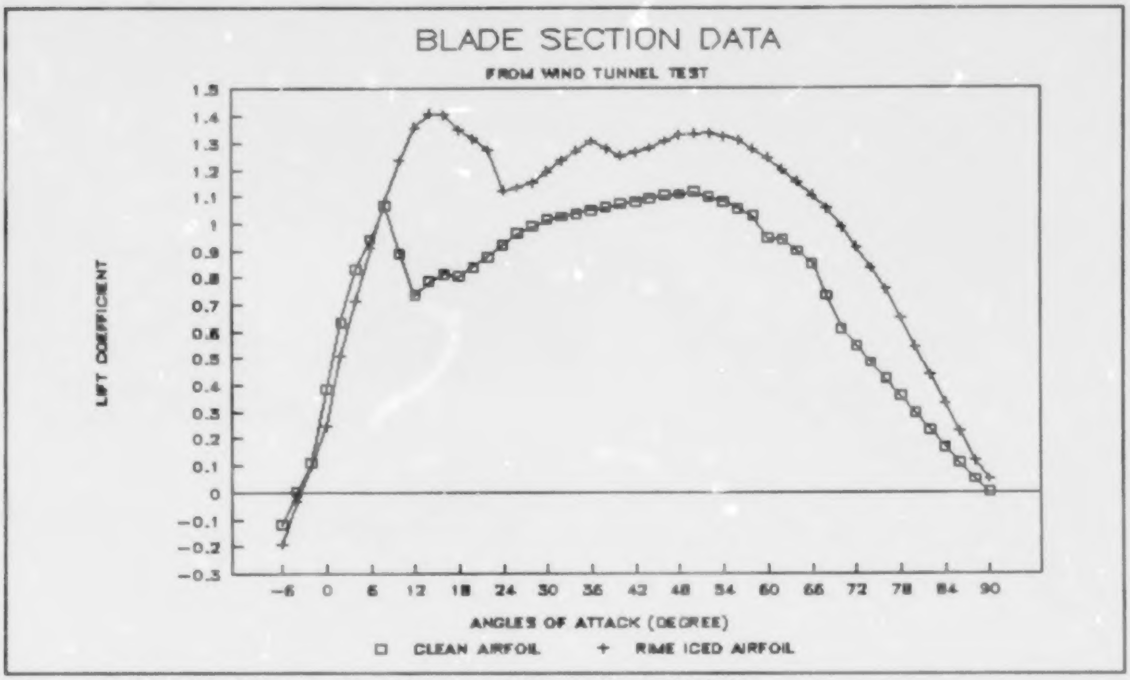


Figure 9. Lift Coefficients for Clean and Rime Iced Airfoil

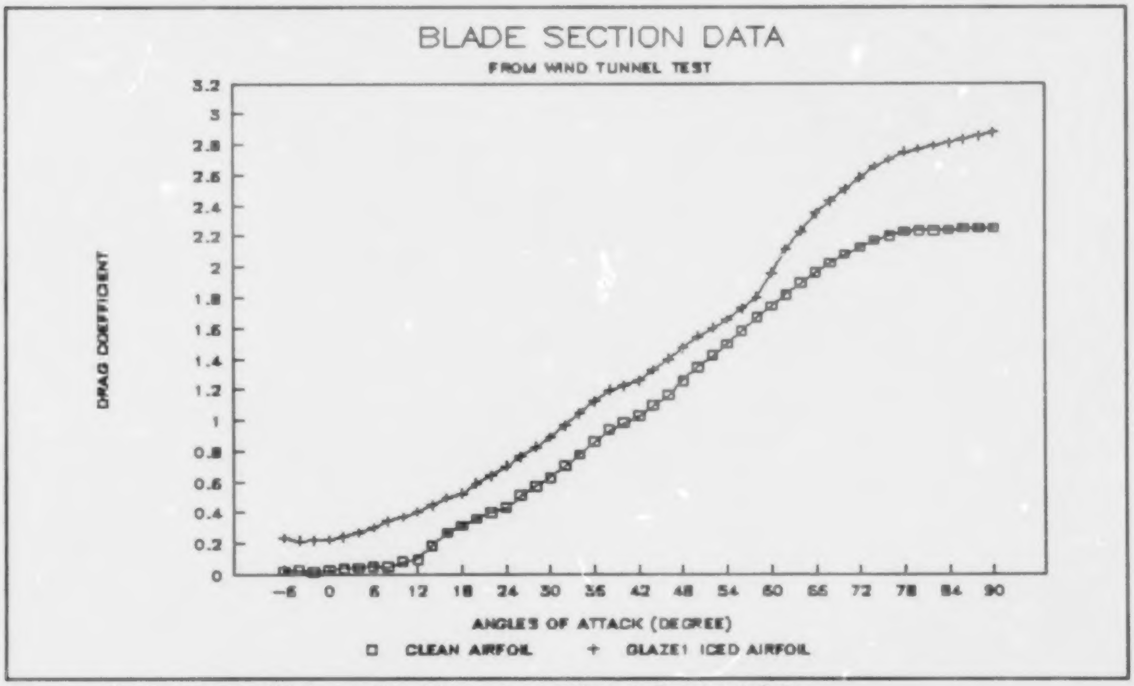


Figure 10. Drag Coefficients for Clean and Glaze1 Iced Airfoil

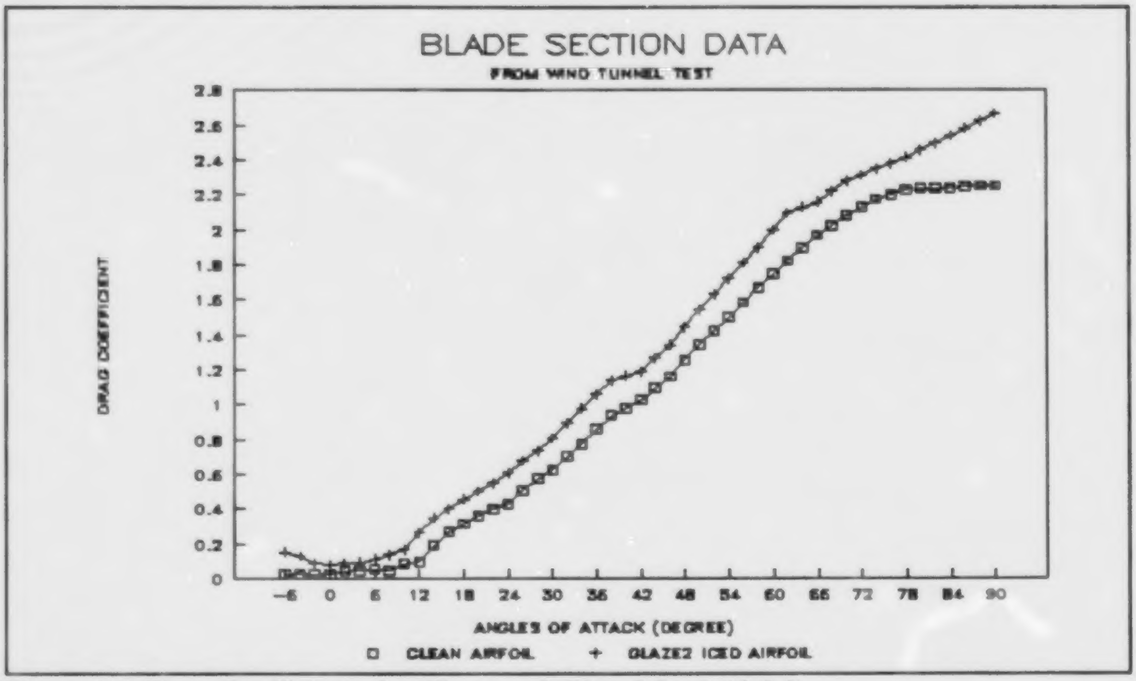


Figure 11. Drag Coefficients for Clean and Glaze2 Iced Airfoil

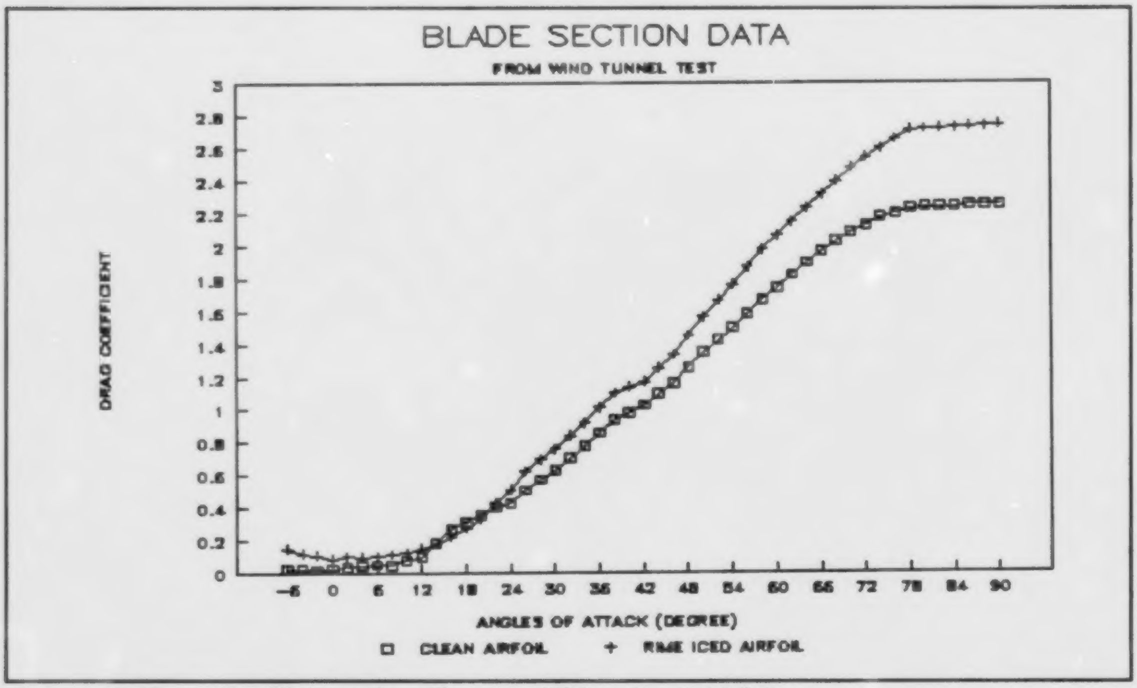


Figure 12. Drag Coefficients for Clean and Rime Iced Airfoil

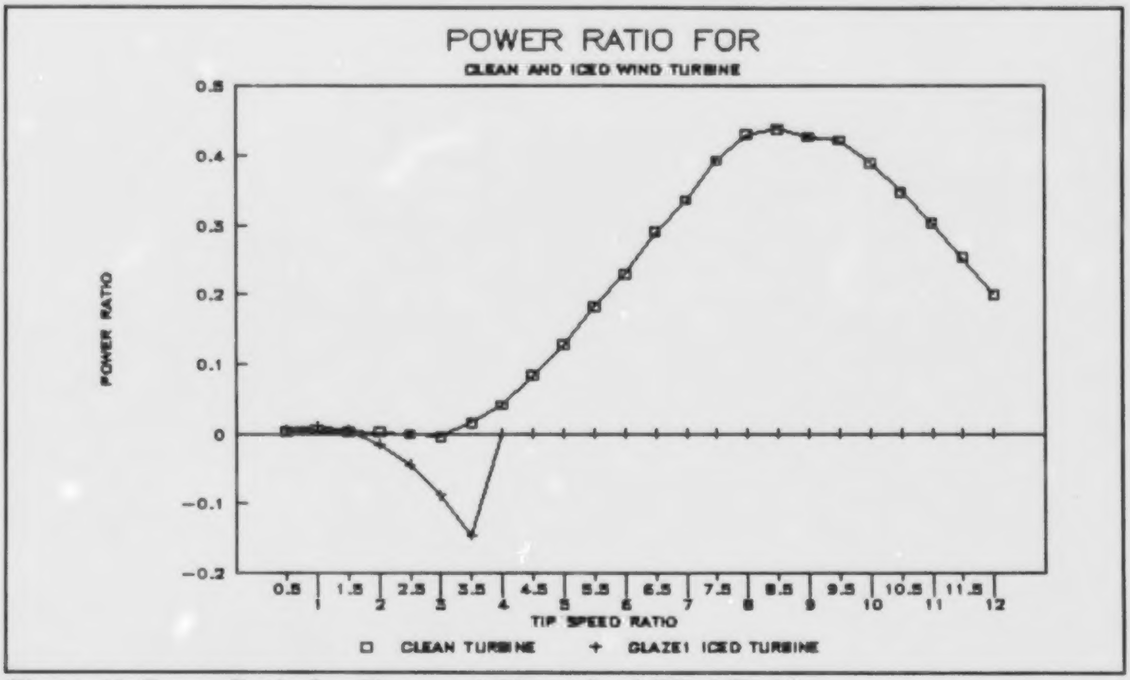


Figure 13. Power Ratio for Clean and Glaze1 Iced Wind Turbine

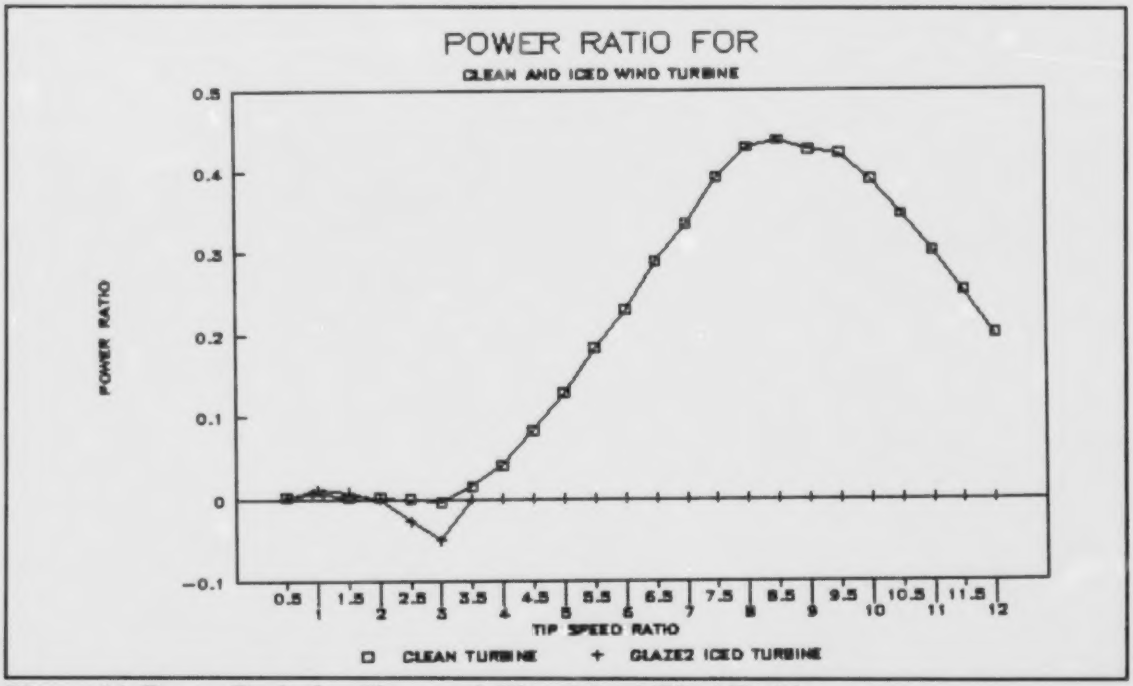


Figure 14. Power Ratio for Clean and Glaze2 Iced Wind Turbine

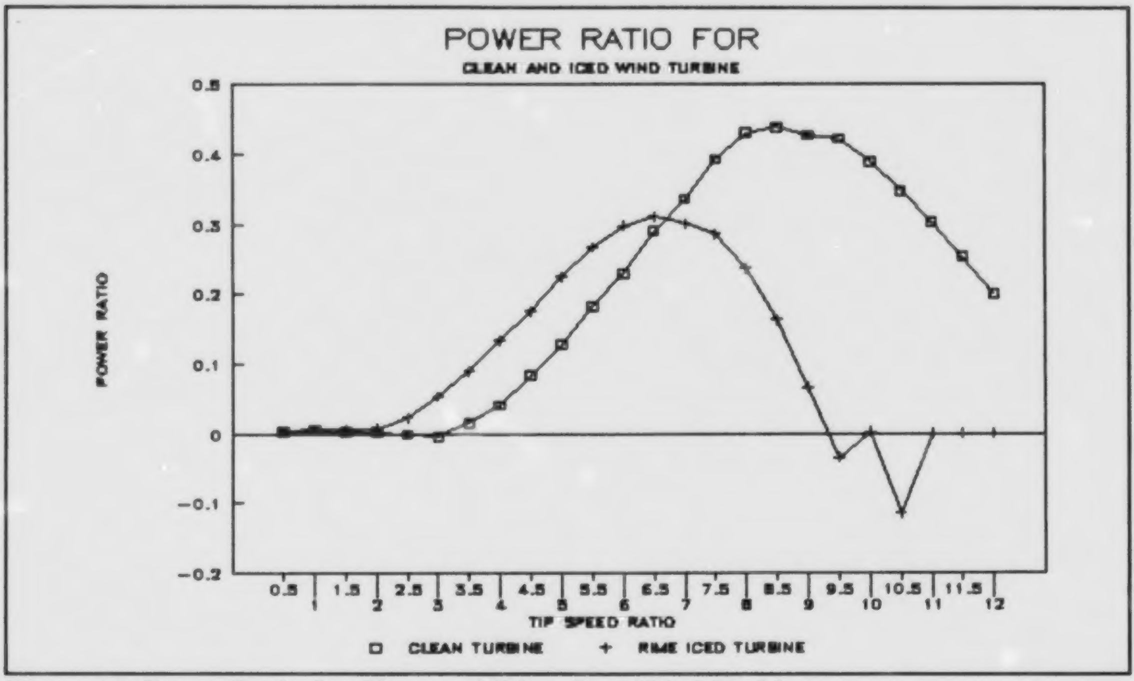
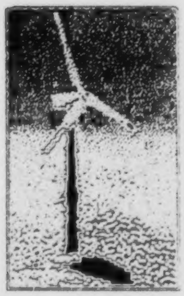


Figure 15. Power Ratio for Clean and Rime Iced Wind Turbine



WINDFARMS:
A STATUS REPORT

SOUTHWEST ALBERTA RENEWABLE ENERGY INITIATIVE

MARY-ELLEN JONES, P.ENG.
ALBERTA OFFICE OF RENEWABLE ENERGY TECHNOLOGY
INFORMATION CENTRE MANAGER

EARLY BEGINNINGS

In 1986 Premier Don Getty announced that the Alberta government would launch a program to introduce large scale renewable energy projects in Alberta. The prime purpose of the program would be to stimulate economic growth while developing environmentally safe ways of harnessing the province's renewable sources of power.

A decade of research had shown that Alberta was ideally suited to the development of solar- and wind-based energy technologies. The Southwest part of the province was chosen as the best place to begin a program because of its abundant, year-round supply of wind and sun.

Premier Getty's commitment led to the creation of the Southwest Alberta Solar, Wind and Renewable Energy Advisory Board. Consisting of representatives from the Pincher Creek area and chaired by Dr. John Rottger, the Advisory Board prepared a detailed report with specific recommendations for a prospective program.

Those recommendations shaped the Southwest Alberta Renewable Energy Initiative (SWAREI) announced by Energy Minister Rick Orman in December 1989. SWAREI is funded by the Alberta government through the Alberta Heritage Savings Trust Fund with a budget of $3 million over three years. It is the largest renewable energy program in Western Canada as well as the largest wind energy project in Canada.

MANDATE

Alberta Office of Renewable Energy Technology

The Alberta Office of Renewable Energy Technology (AORET) was established in May 1990 to implement and manage SWAREI. The Office has an independent six-person Board of Directors chaired by Pincher Creek resident Dr. John Rottger. The Board reports directly to Alberta's Minister of Energy and receives administrative support from the Department of Energy.

The key operational functions of AORET are to: manage SWAREI; advise the Alberta government on renewable energy technologies; promote the development and use of renewable energy technologies; and liaise and promote co-operation with the private sector, research agencies, universities and other government organizations in renewable energy research and development.

Southwest Alberta Renewable Energy Initiative

SWAREI supports the development of wind energy, solar energy, small hydro, methane recovery from landfills and energy from waste. Areas of interest also include significant industrial energy conservation measures and energy efficiency.

The Initiative has the following objectives:

1. To promote the development of environmentally acceptable renewable energy and energy conservation technologies suitable to Alberta's climate.
2. To encourage and support the economic diversification of the Pincher Creek/Crowsnest Pass area through the development and enhancement of local business, expertise and know-how in the areas of renewable energy and energy conservation technologies.
3. To encourage private developers to use existing technologies in the construction and operation of significant demonstration projects of renewable energy generation, energy recovery and energy conservation measures.
4. To disseminate information on renewable energy technologies through the AORET Information Centre in Pincher Creek.

ASSISTANCE AVAILABLE

The Initiative offers three types of assistance: financial assistance; power allocation; and information dissemination.

Funding Assistance

Private investors can apply for financial and technical assistance for field testing of renewable energy projects. As a general rule, financial assistance is available in the form of a non-repayable grant of up to a maximum of $200,000 per project in a fiscal year, subject to the availability of funds and suitability to program objectives. It is expected that the private sector will not only lead in the construction and subsequent operation of the projects, but will also provide substantial financial support.

Allocation

AORET has been granted a total of 12.5 megawatts of power generation capacity under the Alberta Small Power Research and Development Program. This program allows small producers of power to sell electricity to the provincial power grid under ten- to twenty-year contracts at preferential rates.

Payment for electricity generated under the program can be selected in one of two ways: a fixed price per kilowatt hour or a price which is adjusted annually for inflation. Both rates are based on projected 1995 prices and are considerably higher than prices currently being offered by the utilities. This provides small power producers an opportunity to develop their technologies and demonstrate their potential to contribute to long term power requirements in Alberta. In 1990-91 AORET transferred 12.3 megawatts of its power allocation to three separate renewable energy projects.

ACHIEVEMENTS IN 1990-91

Administration

During its first year, AORET set up administrative procedures, prepared program guidelines and identified the portion of the province where SWAREI applies.

The Office has designed a two-stage submission process to facilitate planning and to save applicants time and effort. First, the applicant submits an Expression of Interest, a short letter outlining the proposed project, to the AORET Information Centre in Pincher Creek. The Expression of Interest is evaluated by a Review Committee on its technical and economic merits, management capabilities and the degree to which it meets program objectives.

If the criteria are met, the applicant progresses to the second stage and is asked to submit a formal Proposal. The formal Proposal expands on the information given in the Expression of Interest and includes economic calculations, a detailed workplan and a budget. Generally, proposals are reviewed and evaluated by the AORET Board and outside experts within six weeks of receipt.

Information and Assistance

The AORET Information Centre was established in Pincher Creek during the summer of 1990. The Centre has been instrumental in the promotion of SWAREI within the renewable energy industry and has provided information on technologies to the general public. During 1990-91 its manager participated in two national conferences and made eight presentations to groups in Southern Alberta. In addition, five workshops on renewable energy and two workshops on energy efficiency were held at the Information Centre during the winter months.

The Centre also provides literature on renewable energy and energy conservation and answers questions from interested callers and visitors.

Projects Approved in 1990-91

The Alberta Office of Renewable Energy Technology initiated its first call for Expressions of Interest in June of 1990. A number of innovative submissions were received, representing a wide variety of potential directions for SWAREI to pursue. During 1990-91, AORET received 32 Expressions of Interest and 17 Proposals for development/demonstration funding. Of these, six projects were approved for SWAREI contributions in 1990-91 and two in 1991-92.

The largest project is a 36-turbine demonstration wind farm to be located at Cowley Ridge, northwest of Pincher Creek. Although the project received no funding, a transfer of nine megawatts of SWAREI's capacity allocation was approved. The wind farm is expected to cost $11.4 million over three years and will be financed entirely by U.S. Windpower Incorporated of Livermore, California. Construction, operation and maintenance of the wind farm will be done by an Alberta company, Wind Power Incorporated.

A second wind project will provide a testing ground for Canadian-made wind turbine technology. Adecon Alberta Incorporated will test a wind power plant at a site northeast of Pincher Creek. SWAREI capacity allocation of 1.5 megawatts will be transferred to the project.

A proposal to build a 2.4 megawatt hydroelectric plant at the Waterton Dam was also approved. The plant received 1.8 megawatts of SWAREI allocation and 0.6 megawatts from the Small Power Research and Development Program. It will be built and financed largely by Canadian Hydro Developers Incorporated of Calgary.

All three projects are scheduled to begin generation of electricity in 1991-92. When operational, they will have a combined nominal generating capacity of 12.9 megawatts.

Two Alberta companies received funding for projects involving solar- and wind-powered water pumps. Canadian Agtechnology Partners of Olds, Alberta will conduct a demonstration project using solar- and wind-powered water pumps to provide water for wildlife habitat near the Oldman River Dam.

Maverick Wind Energy of Twin Butte, Alberta will develop and demonstrate a wind-powered water pump beginning in 1991. The existing water pumping design developed in Fort Macleod will be modified using University of Calgary Professor Dr. J.A.C. Kentfield's expertise to refine the aerodynamics of the wind turbine rotor.

All wind projects will benefit from a wind energy survey of the Pincher Creek/Crowsnest Pass area to be conducted by meterologist Dr. James Salmon. When completed, this project will provide the data necessary to select the best locations for future wind turbine installations.

A test site established at Lethbridge in 1982 to provide independent testing of wind- and solar-powered wind pumpers came under the management of SWAREI in April 1990. Because the original site required considerable renovation it was decided that a new facility, to be called the Alberta Renewable Energy Test Site, would be built near Pincher Creek. When the new site is completed in 1992, it will replace the Lethbridge facility. The new location will be much more accessible to users and will allow it to be more closely integrated within SWAREI.

ILES-DE-LA-MADELEINE
PARC D'ÉOLIENNES - 5MW

ETUDE D'AVANT-PROJET

OBJECTIF

Réduire le déficit d'opération de la production d'électricité aux Iles-de-la-Madeleine par l'utilisation de l'énergie Eolienne.

MÉTHODOLOGIE (ÉTAPES)

Etudier différents concepts (taille) de base

Etudier différents sites

Déterminer le coût actualisé du Parc

Estimer les coûts évités de production avec diésels

MICHEL MORVAN
Ingenieur de projet

HYDRO-QUEBEC

ETAPE I : ETUDE DE CONCEPTS

CONCEPTS ENVISAGÉS (CONTRAINTE = ÉPROUVÉS ET SANS MODIFICATIONS)

Les tailles proposées par les fournisseurs ont été regroupées selon trois concepts:

Concept I : Parc de 33 Eoliennes de 150 kW

Concept II : Parc de 17 x 300 kW; 18 x 275 kW; 20 x 250 kW

Concept III : Parc de 11 Eoliennes de 450 kW

SITE CONSIDÉRÉ A CETTE ÉTAPE: Grosse-Ile

DISPOSITION DES MACHINES AU SITE A ÉTÉ FAITE SELON:

- Facteurs d'amplification des vents
- Axe des vents dominants
- Contraintes de relief et d'accès
- Minimiser le déboisement

ETAPE I : ETUDE DE CONCEPTS

RÉSULTATS DE LA COMPARAISON TECHNO-ÉCONOMIQUE

ASPECT TECHNIQUE

- Concepts très similaires
- Concepts de moindre taille possèdent plus d'heures d'opération
- Concept de 450 kW bénéficie et utilise l'expérience gagnée.

ASPECT ÉCONOMIQUE (TABLEAU 1)

- Concepts de plus grande taille donnent un coût actualisé plus faible

CONCLUSION

Eolienne de 450 kW a été retenue

Tableau 1

		Coût total Parc (millions $)	Énergie annuelle GWh brute	Coût comparatif
Concept I				
	150 kW	12,73	22,30	1,22
	150 kW	13,20	22,63	1,24
	150 kW	15,52	26,36	1,25
Concept II				
	300 kW	10,76	23,98	1,00 *
	275 kW	9,61	17,75	1,17
	250 kW	10,40	18,15	1,23
	250 kW	9,50	15,78	1,28
	250 kW	10,18	17,74	1,23
Concept III				
	450 kW	9,63	21,95	1,02 *
	450 kW	9,75	21,64	1,01 *

ETAPE II : ÉTUDE DE SITES

SITES CONSIDÉRÉS (Figure 1)

- Grosse-Ile
- Buttes Pelées
- Dune du Nord
- Cap-au-Trou

CARACTÉRISTIQUES GÉNÉRALES

(Voir tableau 2)

OPTIMISATION DES SITES (Figures 2,3,4,5)

- Concept de 450 kW
- Carte des facteurs d'amplification pour maximiser le potentiel d'énergie
- Réduction des effets de sillage
- Contraintes topographiques (relief)
- Contraintes du milieu (déboisement, accès, habitation)

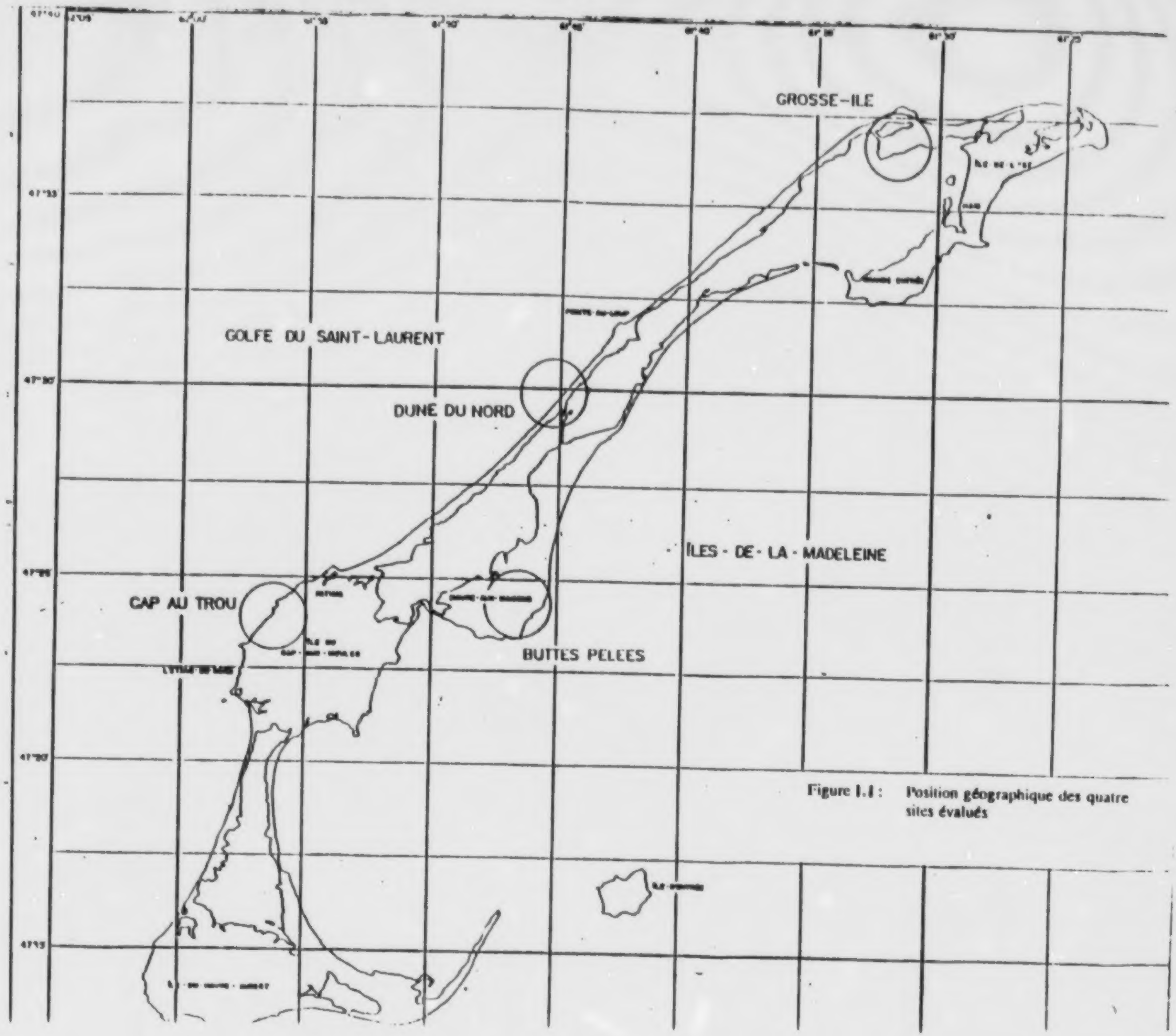

GROSSE-ILE
GOLFE DU SAINT-LAURENT
DUNE DU NORD
ÎLES - DE - LA - MADELEINE
CAP AU TROU
BUTTES PELEES

Figure I.1 : Position géographique des quatre sites évalués

TABLEAU 2

CARACTÉRISTIQUES GÉNÉRALES DES SITES

DESCRIPTION	GROSSE-ILE	DUNES-NORD	BUTTES PELÉES	CAP-AU-TROU
Caractéristiques du terrain	Collines à sommets les plus élevés	Littoral à relief très accidenté	Collines à sommets élevés (pentes fortes)	Plateau de falaise sur Le littoral
Type de sol considéré	Roc	Sable	Roc	Roc
Caractéristiques de la végétation	Dense, couverture végétale 4 à 6 mètres de hauteur	couche d'herbes fragile	Prairie	Mauvaises herbes boisée en partie
Vitesse des vents et facteurs d'amplification	Supérieure à la moyenne	Moyenne	Supérieure à la moyenne	Faible comparée à la moyenne
Accessibilité	Assez facile	Excellente	Très difficile	Facile
Autres	Près d'une tour de télécomm.	Pas d'habitations permanentes	Proximité de l'aéroport et zone urbaine	Proximité nouvelle centrale
Intégration du réseau	Poste existant à moins d'un km	Pas de poste à proximité	Poste existant à environ 3 km	Pas de poste à proximité

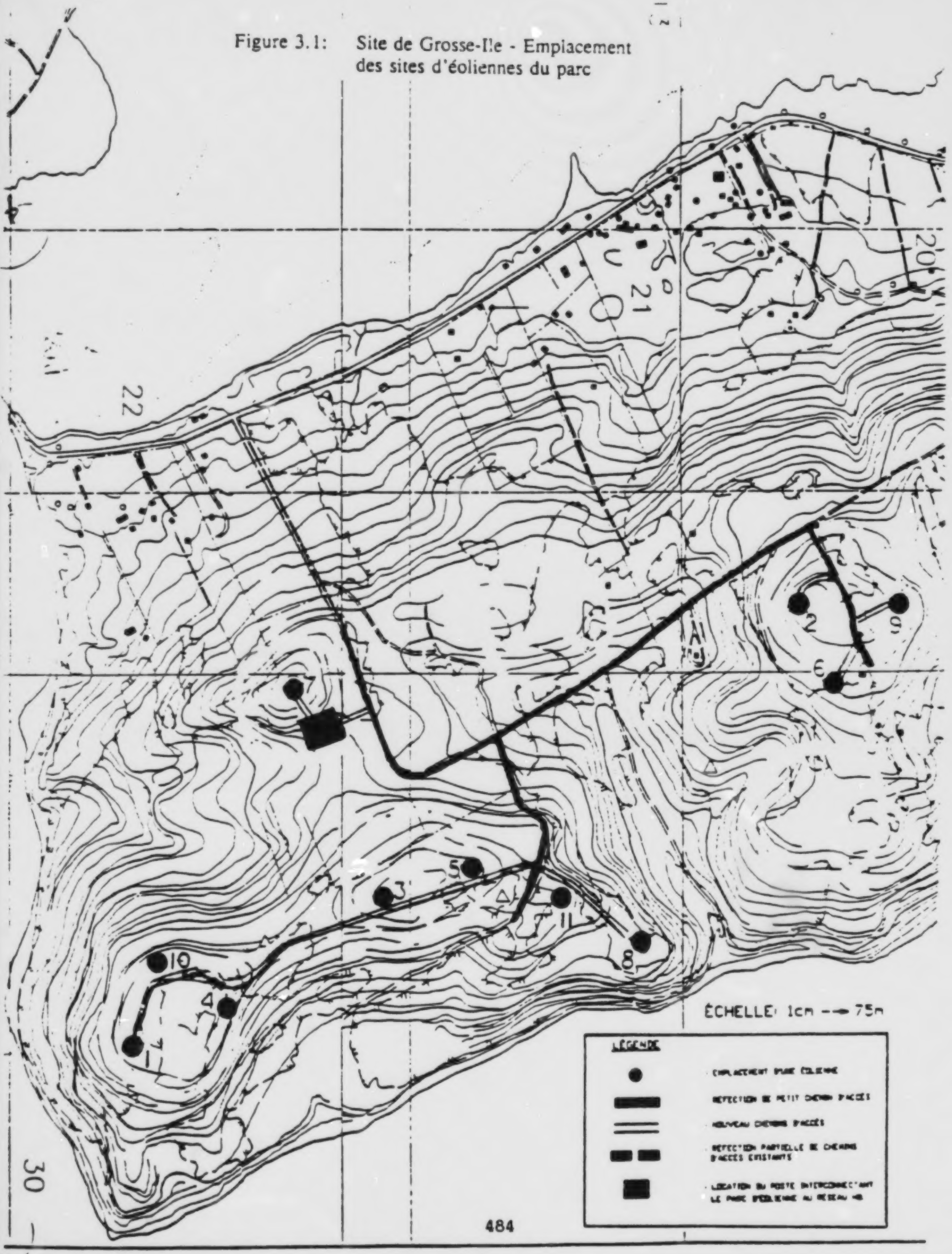
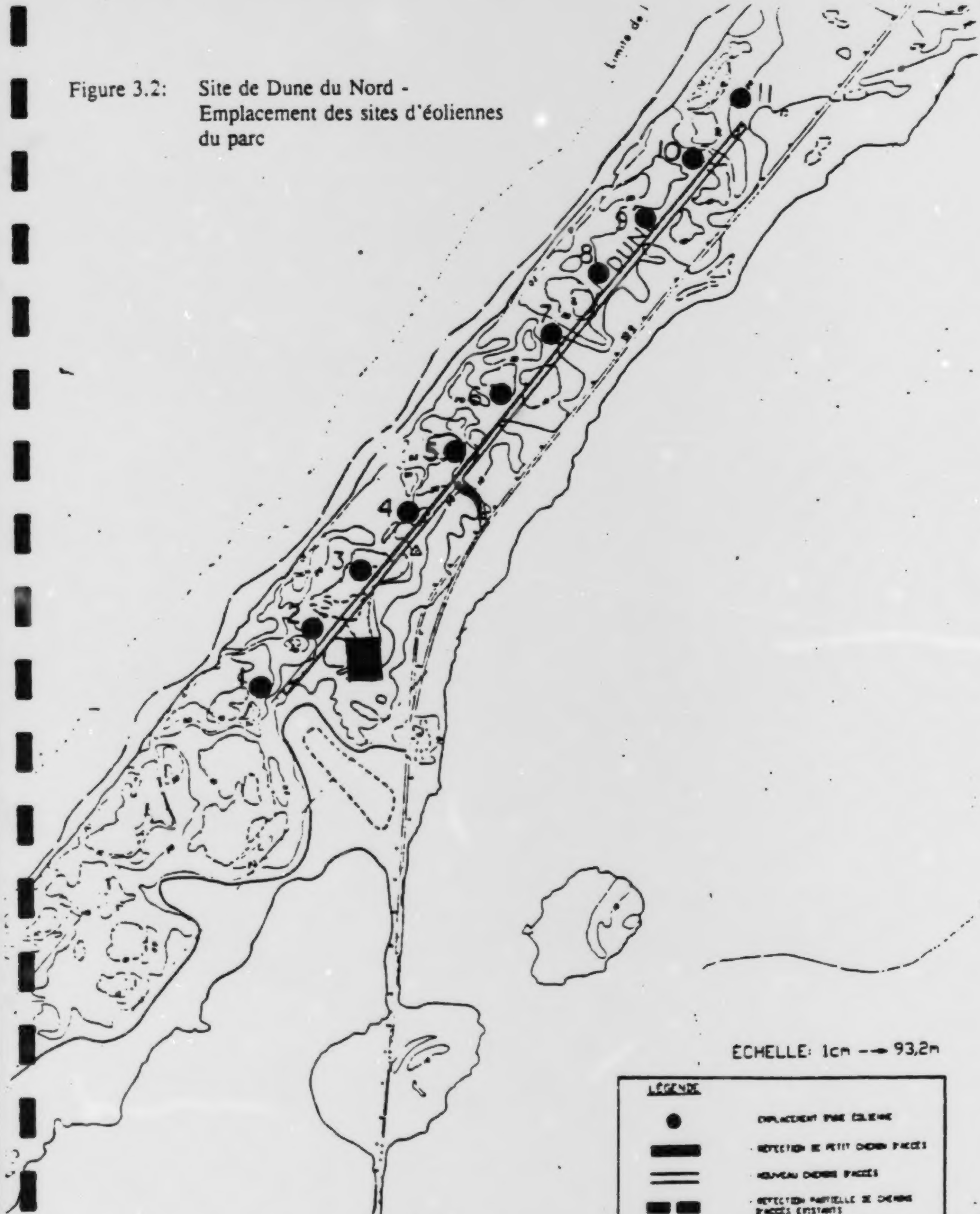


Figure 3.1: Site de Grosse-Ile - Emplacement des sites d'éoliennes du parc

22
21
20
1
2
3
4
5
6
8
9
10
11
ÉCHELLE: 1cm → 75m
LÉGENDE
● EMPLACEMENT D'UNE ÉOLIENNE
RÉFECTION DE PETIT CHEMIN D'ACCÈS
NOUVEAU CHEMINS D'ACCÈS
RÉFECTION PARTIELLE DE CHEMINS D'ACCÈS EXISTANTS
LOCATION DU POSTE INTERCONNECTANT LE PARC D'ÉOLIENNE AU RÉSEAU HQ

Figure 3.2: Site de Dune du Nord - Emplacement des sites d'éoliennes du parc


Limite de l
11
10
9
8
DUNE
6
5
4
3
2
1
PONT
du
DÉTROIT
ÉCHELLE: 1cm --→ 93,2m
LÉGENDE
● EMPLACEMENT D'UNE ÉOLIENNE
RÉFECTION DE PETIT CHEMIN D'ACCÈS
NOUVEAU CHEMINS D'ACCÈS
RÉFECTION PARTIELLE DE CHEMINS D'ACCÈS EXISTANTS
LOCATION DU POSTE INTERCONNECTANT LE PARC D'ÉOLIENNE AU RÉSEAU HQ

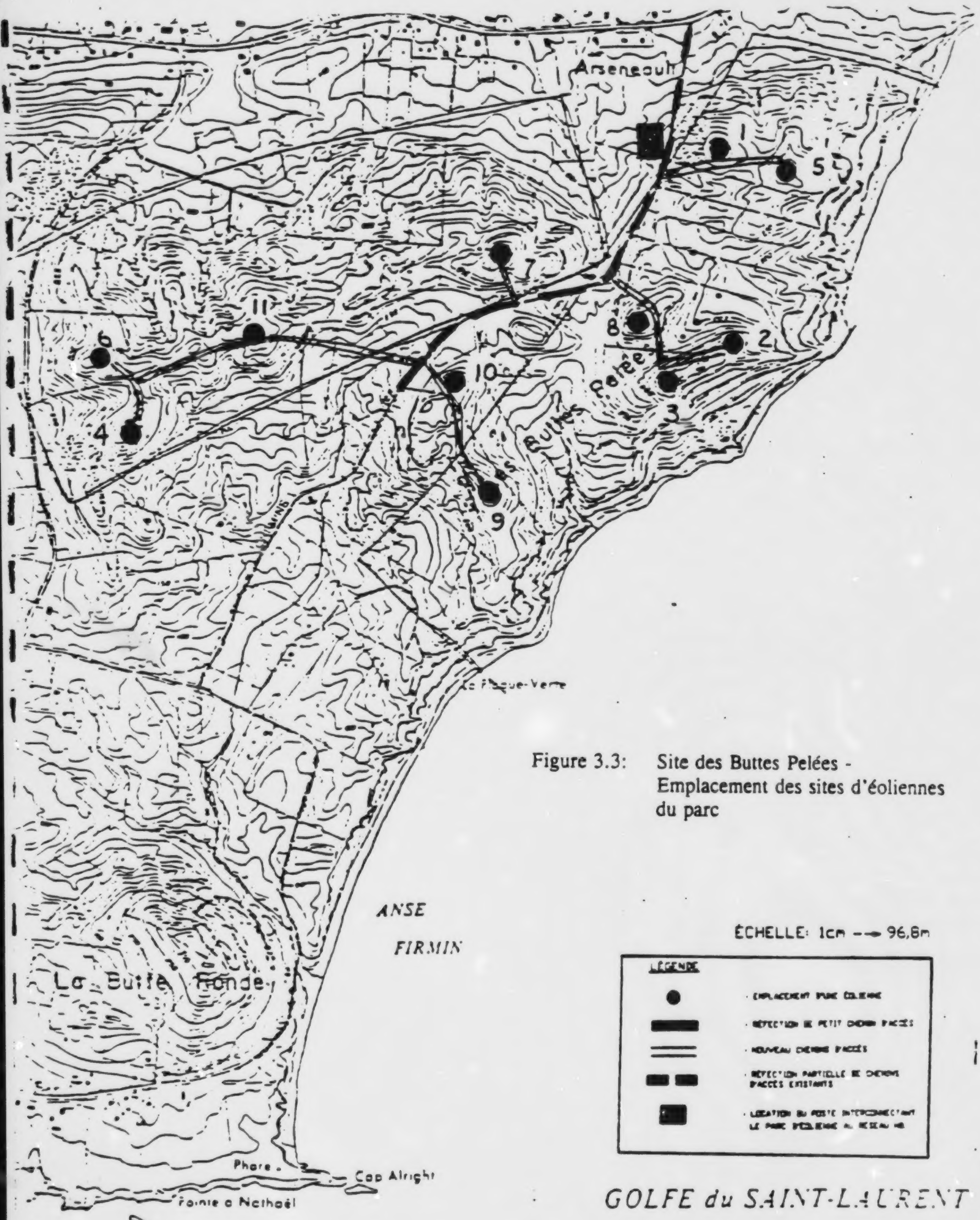
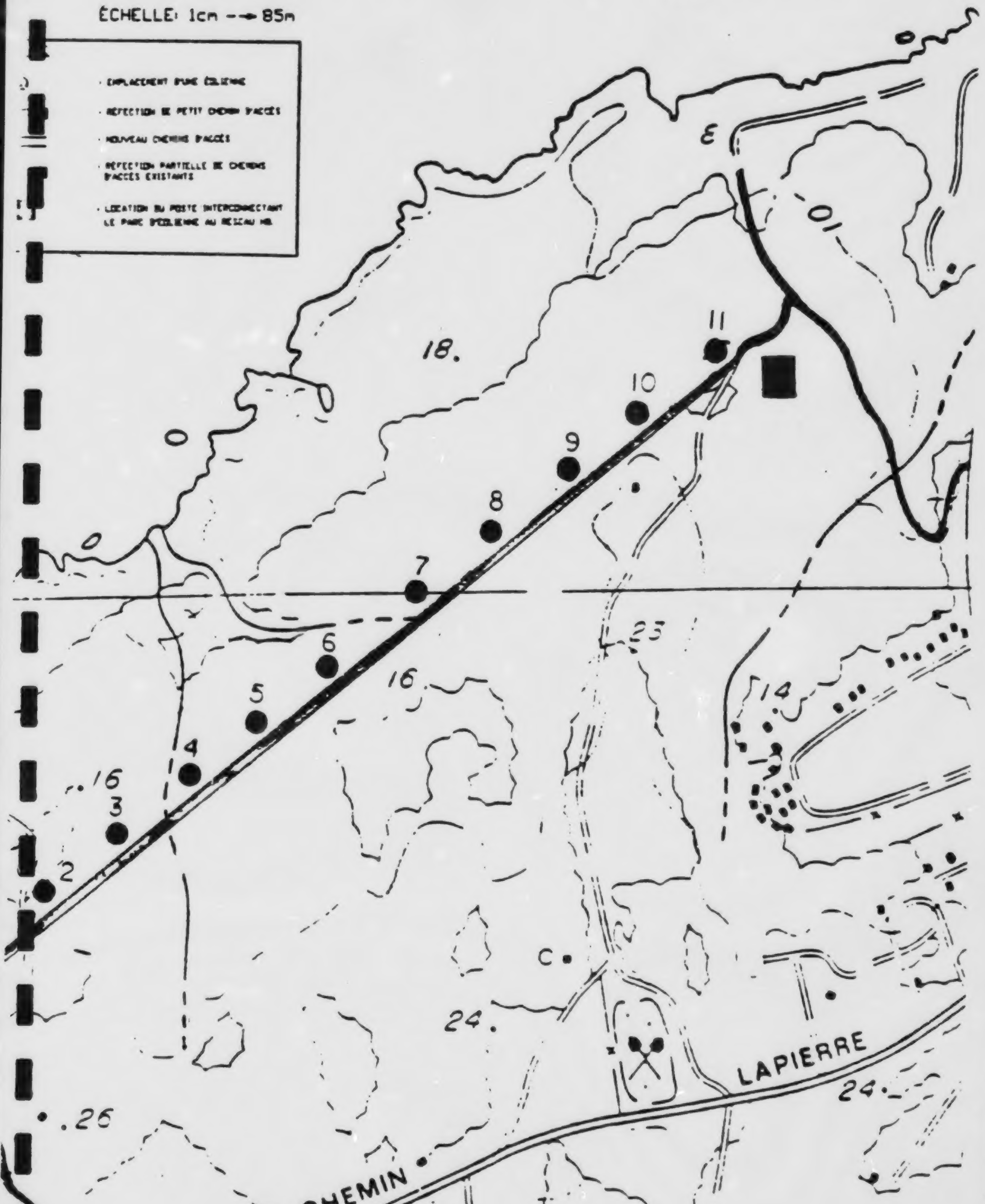

Arseneault
1
5
7
8
2
11
6
10
3
4
9
Buttes Pelées
La Pique-Verte
ANSE
FIRMIN
La Butte Ronde
Phare
Cap Alright
Pointe à Nathaël
GOLFE du SAINT-LAURENT
ÉCHELLE: 1cm —→ 96,6m
LÉGENDE
· EMPLACEMENT D'UNE ÉOLIENNE
· RÉFECTION DE PETIT CHEMIN D'ACCÈS
· NOUVEAU CHEMINS D'ACCÈS
· RÉFECTION PARTIELLE DE CHEMINS D'ACCÈS EXISTANTS
· LOCATION DU POSTE INTERCONNECTANT LE PARC D'ÉOLIENNE AU RÉSEAU HQ

Figure 3.3: Site des Buttes Pelées - Emplacement des sites d'éoliennes du parc

Figure 3.4: Site du Cap au Trou - Emplacement des sites d'éoliennes du parc


ÉCHELLE: 1cm --→ 85m
· EMPLACEMENT D'UNE ÉOLIENNE
· RÉFECTION DE PETIT CHEMIN D'ACCÈS
· NOUVEAU CHEMINS D'ACCÈS
· RÉFECTION PARTIELLE DE CHEMINS D'ACCÈS EXISTANTS
· LOCATION DU POSTE INTERCONNECTANT LE PARC D'ÉOLIENNE AU RÉSEAU HQ
2
3
4
5
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10
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18.
16
.16
23
14
01
24.
24.
.26
C
CHEMIN LAPIERRE

ÉTAPE II : ÉTUDE DE SITES

ÉNERGIE POTENTIELLE BRUTE

Grosse-Ile	22 200 MWh
Buttes Pelées	23 035 MWh
Dune du Nord	16 990 MWh
Cap-au-trou	14 750 MWh

RESULTATS DE LA COMPARAISON TECHNO-ECONOMIQUE

ASPECT TECHNIQUE

Un parc composé de 11 Éoliennes de 450 kW peut être réalisé à tous les sites.

ASPECT PARTICULIER

Tour de communication	Grosse-Ile
Aéroport	Buttes Pelées

ASPECT ÉCONOMIQUE (TABLEAU 3)

Sites Grosse-Ile et Buttes Pelées sont égaux et plus économiques que les deux autres.

Tableau 3

Comparaison économique des sites

	Coût total Parc (millions $)	Énergie annuelle brute GWh	Coût compatif énergétique
Grosse-Ile	9,94	22,20	1,00
Buttes Pelées	10,39	23,04	1,01
Dune du Nord	10,44	16,99	1,31
Cap-au-Trou	10,31	14,75	1,46

ETAPE III : COUT DE REVIENT ACTUALISÉ DU PARC

ANALYSE ÉCONOMIQUE BASÉE SUR COUT DE REVIENT ACTUALISÉ NET D'INFLATION

$$CEP = \frac{CI \times TAF}{DI \times EA \times 10} + E \,\&\, E \quad c/kWh$$

CI = Cout d'investissement en dollars

TAF = Taux d'amortissement fixe, net d'inflation

DI = Disponibilité %

EA = Energie potentielle annuelle, MWh

E & E = Cout annuel d'entretien et d'exploitation, c/kWh

TAUX D'AMORTISSEMENT FIXE

Taux d'intérêt net = 6,20%

Durée de vie = 20 ans

T A F = 8,86%

ETAPE III: COUT DE REVIENT ACTUALISÉ DU PARC

ENERGIE DISPONIBLE (Grosse Ile)

Indisponibilité historique moyenne =	5%
Pertes d'énergie dans système électrique =	1,5%
Arrêt à cause de basses températures = (-30°c)	0%
Total:	6,5%

Disponibilité = 93,5% x 22 200 MWh = 20 760 MWh au réseau électrique

COUT D'ENTRETIEN ET D'EXPLOITATION

BASÉ SUR EXPÉRIENCE DE PARCS D'ÉOLIENNES

E & E = 1 c/kWh = 20 000/an éolienne

Cout estimé d'entretien régulier = 9 100/an éolienne

Autres couts d'exploitation = 10 900/an éolienne (ex: réparations)

ETAPE III : COUT DE REVIENT ACTUALISÉ DU PARC

COUT D'INVESTISSEMENT

Couts estimés complets d'un parc de II éoliennes (450 kW) situées à Grosse-Ile sont de 12 187 000 $.(1990)

Couts incluent les frais directs et indirects ainsi que la réserve pour éventualités (7.5%)

COUT DE REVIENT DE L'ÉNERGIE DISPONIBLE

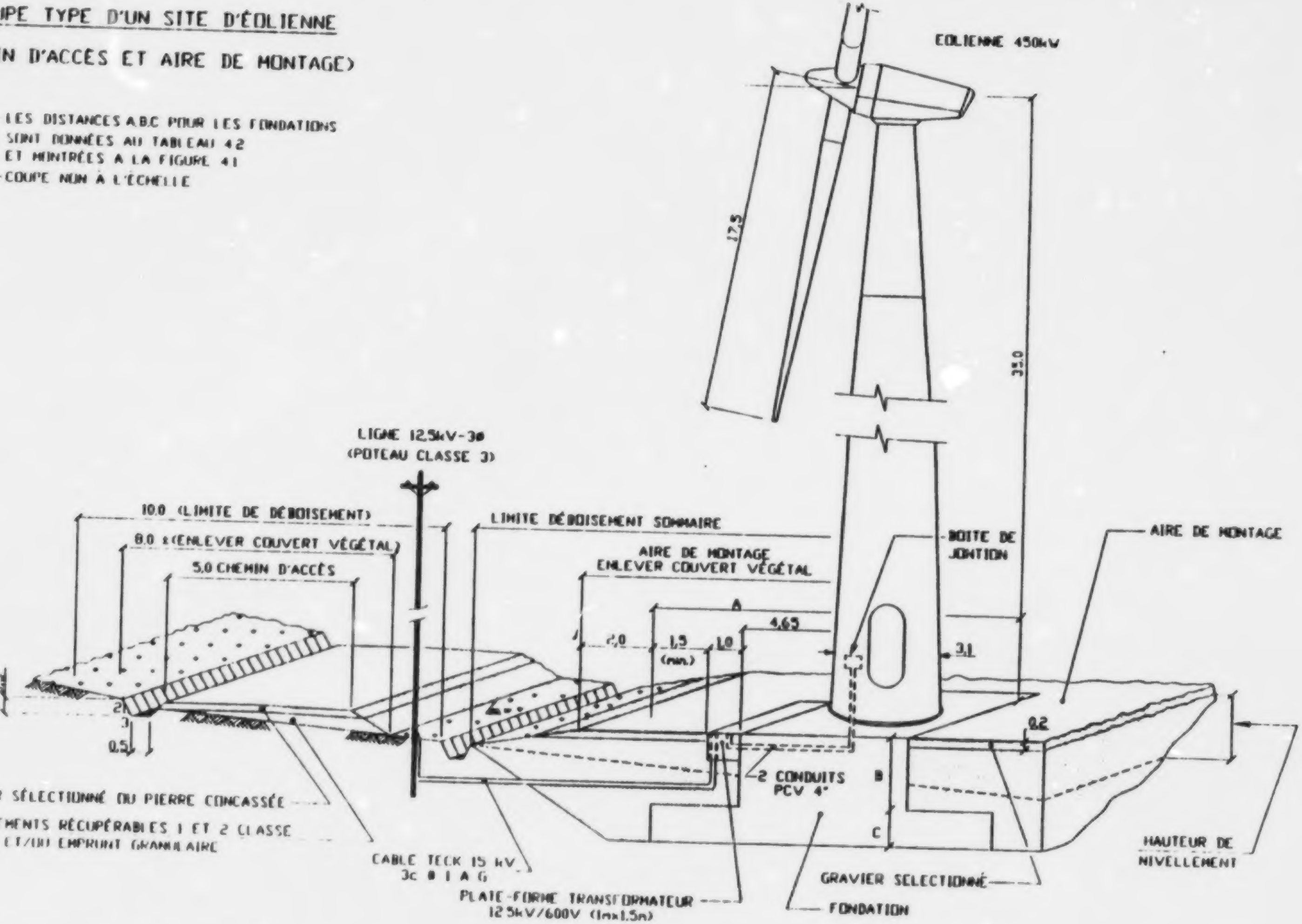
CEP = 6,2 c/kWh

FIGURE 3.4.5

COUPE TYPE D'UN SITE D'ÉOLIENNE

(CHEMIN D'ACCÈS ET AIRE DE MONTAGE)

NOTES: LES DISTANCES A.B.C POUR LES FONDATIONS
SONT DONNÉES AU TABLEAU 4.2
ET MONTRÉES A LA FIGURE 4.1
-COUPE NON À L'ÉCHELLE


EOLIENNE 450kW
17.5
35.0
LIGNE 12.5kV-3ø
(POTEAU CLASSE 3)
10.0 (LIMITE DE DÉBOISEMENT)
8.0 ±(ENLEVER COUVERT VÉGÉTAL)
5.0 CHEMIN D'ACCÈS
LIMITE DÉBOISEMENT SOMMAIRE
AIRE DE MONTAGE
ENLEVER COUVERT VÉGÉTAL
BOITE DE
JONTION
AIRE DE MONTAGE
A
4.65
2.0
1.5
(min.)
1.0
3.1
0.2
0.5
2
3
0.5
B
C
2 CONDUITS
PCV 4"
GRAVIER SÉLECTIONNÉ OU PIERRE CONCASSÉE
TERRASSEMENTS RÉCUPÉRABLES 1 ET 2 CLASSE
ET/OU EMPRUNT GRANULAIRE
CABLE TECK 15 kV
3c # 1 A G
PLATE-FORME TRANSFORMATEUR
12.5kV/600V (1mx1.5m)
GRAVIER SÉLECTIONNÉ
FONDATION
HAUTEUR DE
NIVELLEMENT

ETAPE IV : COUTS ÉVITÉS (DIÉSELS)

NATURE DES COUTS PERTINENTS ÉVITÉS

Carburant

Prolongation de la vie utile

Frais d'entretien variables

Huiles de lubrification

ESTIMATION SOMMAIRE DES COUTS ÉVITÉS

Total couts évités = 6,3 c/kWh (préliminaire)

RÉSUMÉ

Parc de II éoliennes de 450 kW situé à Grosse-Ile serait marginalement intéressant au point de vue économique, sujet à finalisation :

- Etudes d'environnement

- Etudes plus poussées sur les couts évités

- Programme de communication

ÎLES DE LA MADELEINE

Predictions of Annual Energy Production for Selected Wind Farm Sites

Jim Salmon

1435 Colonsay Drive
Burlington, Ontario
L7P 2T8
Tel. (416) 335-6085

1 NUMERICAL MODELS, SITES AND TURBINES

1.1 INTRODUCTION

This report describes numerical modelling studies of the wind energy generation potential at five locations in the Îles de la Madeleine. Four different models of wind turbines, arrayed in a variety of configurations, were considered.

The report is divided into five parts. This introduction provides a very brief description of the numerical models used, the sites considered and the turbines evaluated. The second section describes the wind resource as measured at the Îles de la Madeleine Airport. The next section describes an initial examination of the wind energy potential at each of the sites for three types of arrays of wind turbines. These estimates were determined using the WAsP numerical model. In the penultimate section, the results of a study with the MS-Micro/2 numerical model to optimize the locations in terms of maximizing production of two turbine types (Nordtank NTK 300/31 and Bonus 450) at two sites (Grosse Île and Les Buttes Pellées) is presented. The final section presents some suggestions for improvement and further analysis.

1.2 NUMERICAL MODELS USED

Two numerical models were used in the study, WAsP (including the program PARK) and MS/Micro/2 (along with some new wind energy calculation routines). WAsP is supplied by the Department of Meteorology and Wind Energy, Risø National Laboratory, Denmark while MS-Micro/2 is available from the Canadian Climate Centre of the Atmospheric Environment Service, Canada.

In its manual WAsP (Wind Atlas Analysis and Application Programme) is described as follows. "WAsP ... is a PC program for the horizontal and vertical extrapolation of wind data. It takes into account the effect of different roughness conditions, sheltering effects due to nearby buildings and other obstacles, and modifications of the wind imposed by hills and complex terrain. Thus, it provides the user with means of correcting the basic meteorological data, as well as offering tools for detailed siting of wind turbines."

MS-Micro/2 is also a microcomputer model for the prediction of the effect of complex topography and roughness distributions on the wind regime.

Notable differences between WAsP and MS-Micro/2 are as follows.

1) WAsP includes the facility to correct and treat raw wind data in order to extract the meteorological parameters of interest, namely the frequency and Weibull distribution parameters, by direction, of the incident wind regime.

2) WAsP functions in a point-by-point manner whereas MS-Micro/2 treats the region under consideration as a field and provides values at grid points in the field.

1.3 SITES EXAMINED

Altogether, six sites were examined - the Airport and five candidate wind turbine sites. Analysis of the Airport site was necessary to provide corrections to the Airport climatological wind data for effects due to the terrain surrounding the anemometer located there.

The original turbine candidate sites were: 1) Grosse Île, 2) Les Buttes Pelées, 3) La Dune du Nord, 4) La Dune du Sud - A and 5) La Dune du Sud - B. These sites are described in Appendix A. After discussion with Hydro-Quebéc another potential site was added to the list - Plateau des Caps. This site was situated on the flat, uninhabited "waste-land" bordering the north shore of Île Cap aux Meules approximately between Cap au Trou in the west and Cap de l'Hôpital in the east. It lies at approximately 61°55′W and 47°25′N. After initial examination of the sites, it was decided that La Dune du Sud - B was sufficiently similar to La Dune du Sud - A that it would be adequate to examine only one of these sites. Site A was chosen.

Figures 1a-g are provided to show the location of the origin (0m,0m) of the local metric Cartesian coordinate system set up at each of the sites. The origins are near the centres of each of the figures and are denoted by a crossed circle. The local system is aligned E-W and N-S at the origin. The figures have been extracted from the 1:10,000 Îles de la Madeleines (Plan Photographique) maps (numbered 7 to 19) of the Ministère des Terres et Forêts (Gouvernement de Québec). They are dated 1964 with some revisions in 1977.

Note that there are two figures (1c and 1d) for Les Buttes Pelées. The first corresponds to the origin used with the initial WAsP analysis of the site while the second was used with the MS-Micro/2 optimization exercise for that site. The origin was moved for logistic reasons.

1.4 TURBINES EVALUATED

Four turbines were chosen for evaluation: Micon M450 (250kW nominal), Bonus Combi 275 (275kW), Nordtank NTK 300/31 (300kW) and Bonus 450 (450kW). Some of their characteristics are listed in Table 1 while the power curves are shown in Figure 2. These data were provided by Hydro-Québec.

Note that in the figure, there are two

Table 1 Characteristics of wind turbines studied.

	Nominal Power (kW)	Hub-height (m)	Rotor diameter (m)	Rotation Speed (rot/min)	Number of units for 5MW
Bonus 450	450	35	35	35	11
Nordtank NTK 300/31	300	31	31	35	17
Bonus Combi 275	275	30	27	42	18
Micon M450	250	30	24	44	20

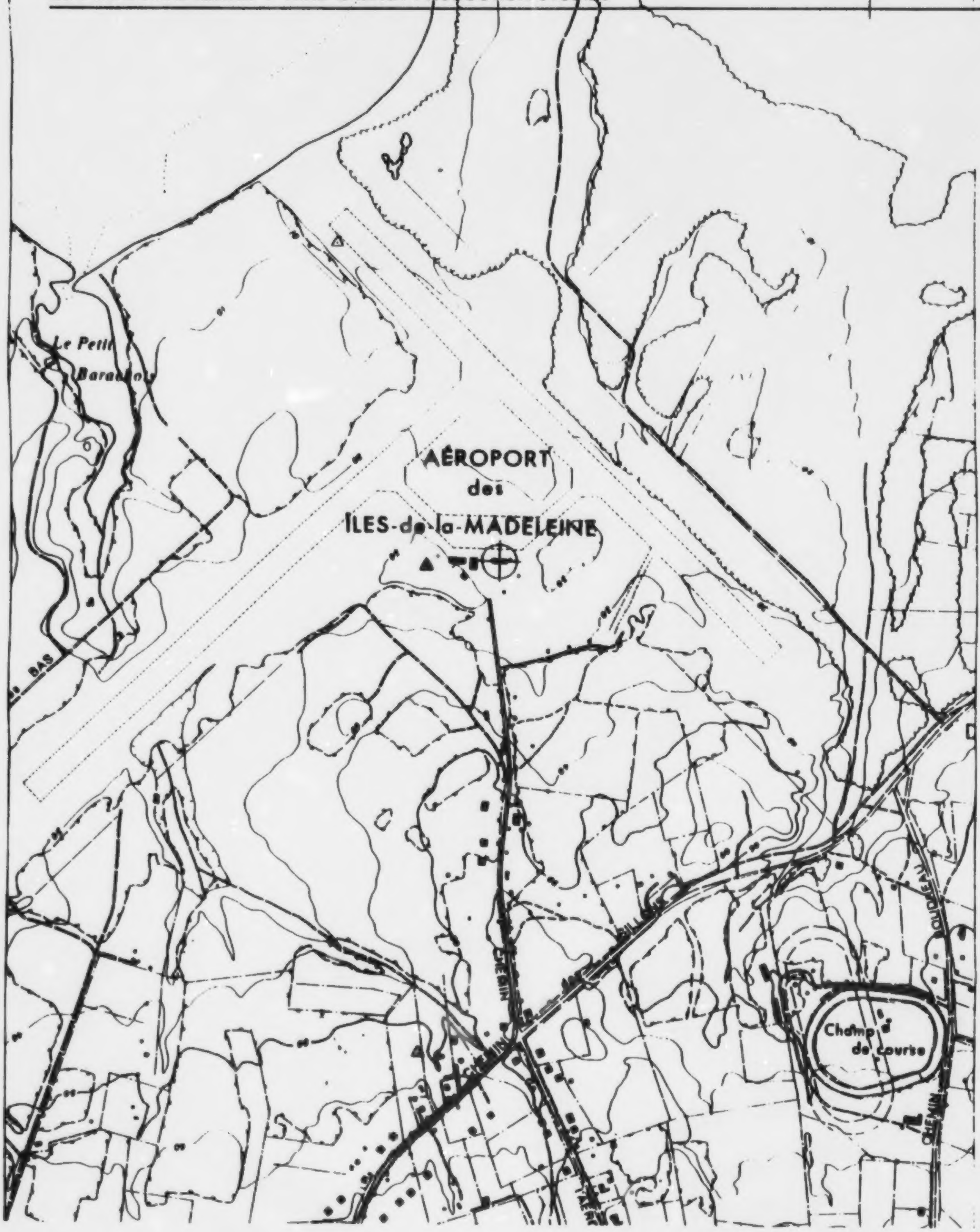

AÉROPORT
des
ÎLES-de-la-MADELEINE
Le Petit
Barachois
BAS
CHEMIN
CHEMIN
Champ de course
CHEMIN

Figure 1 (a) Location of the origin for Îles de la Madeleine Airport.

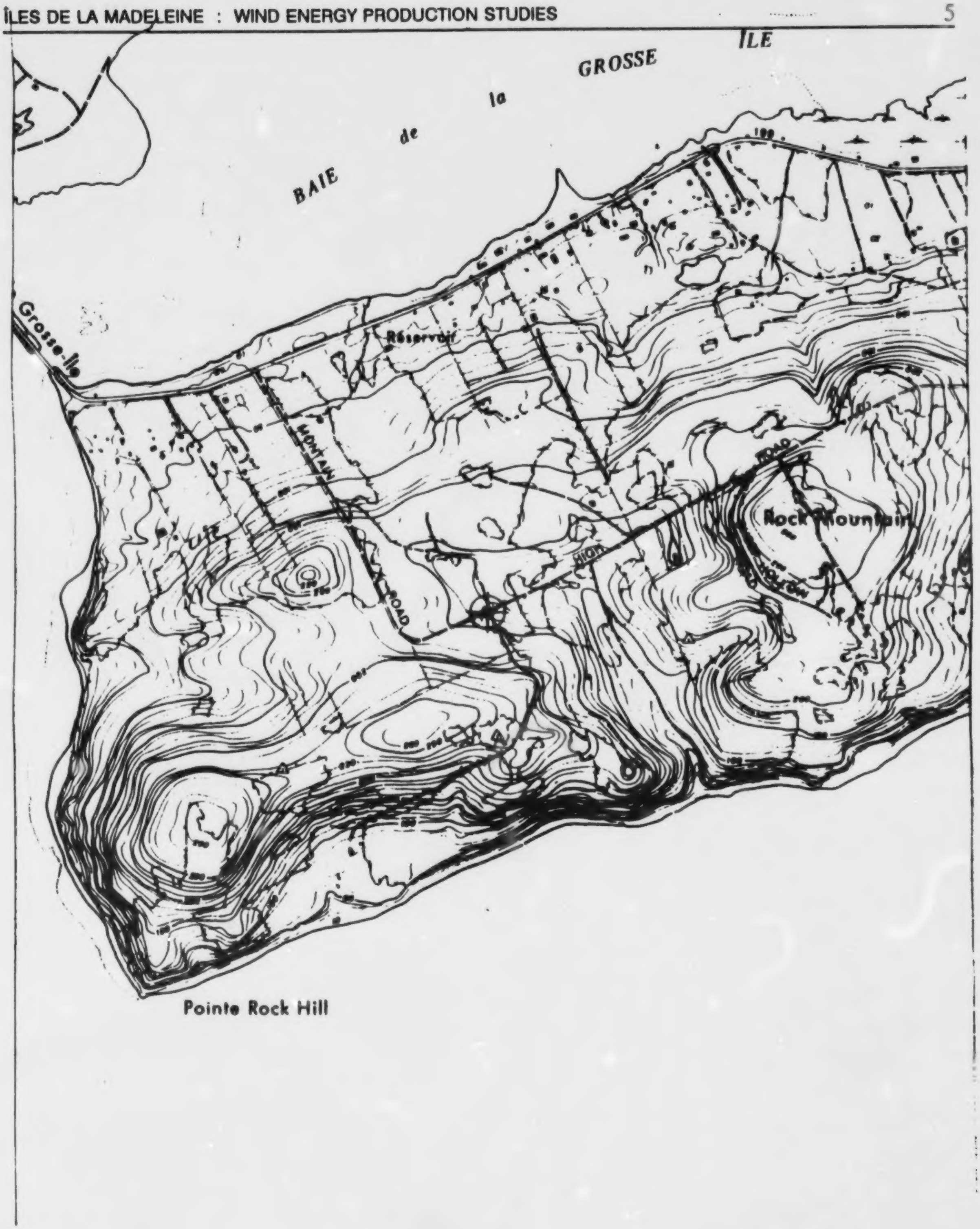

GROSSE ÎLE
BAIE de la
Grosse-Île
Réservoir
MOUNTAIN ROAD
HIGH ROAD
Rock Mountain
Pointe Rock Hill

Figure 1 (b) Location of the origin for Grosse Île.

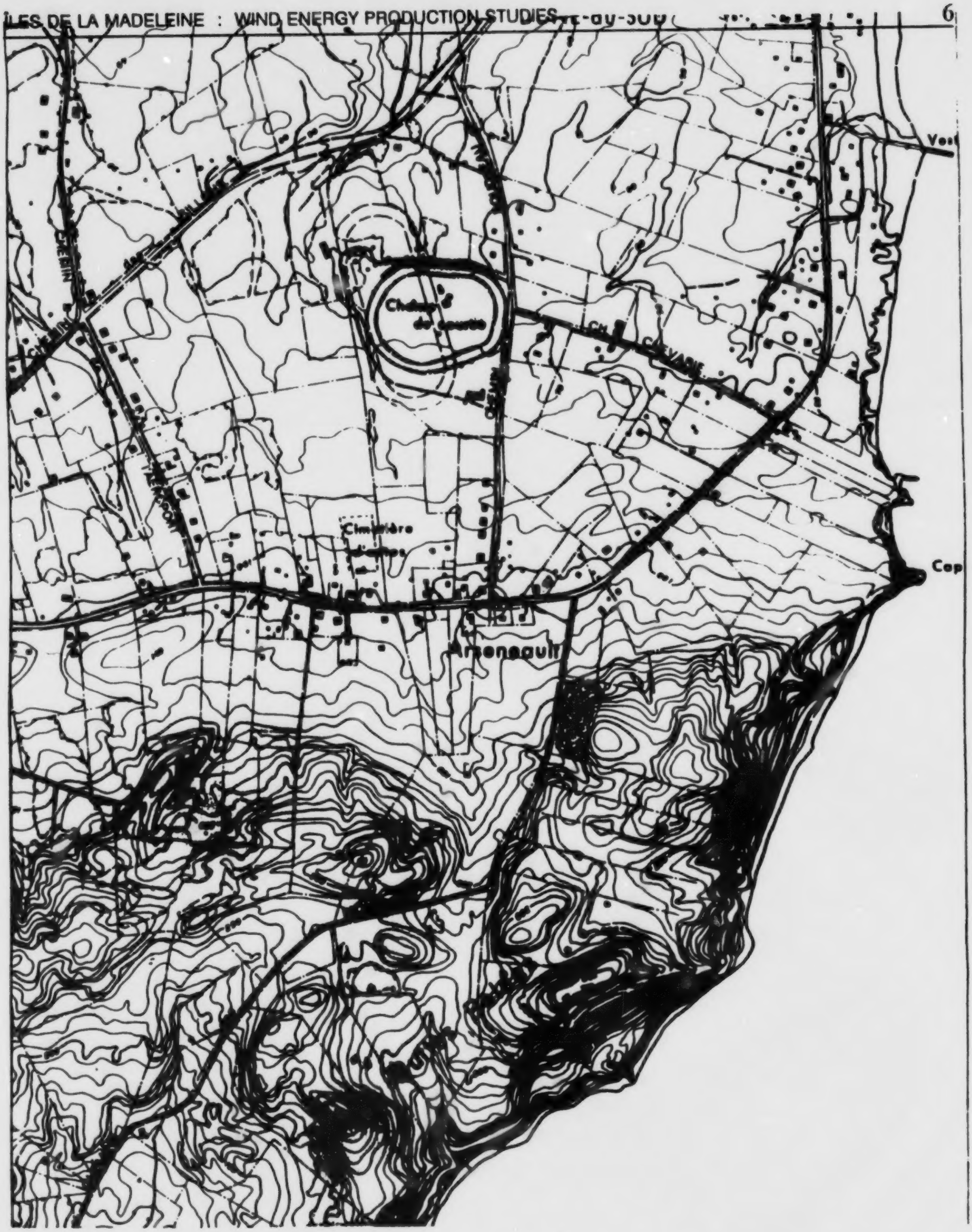

6
Vol
Château de
CH. DU CALVAIRE
Cimetière
Arsenault
Cap

Figure 1 (c) Location of the origin for Les Buttes Pelées WAsP studies (section 3).

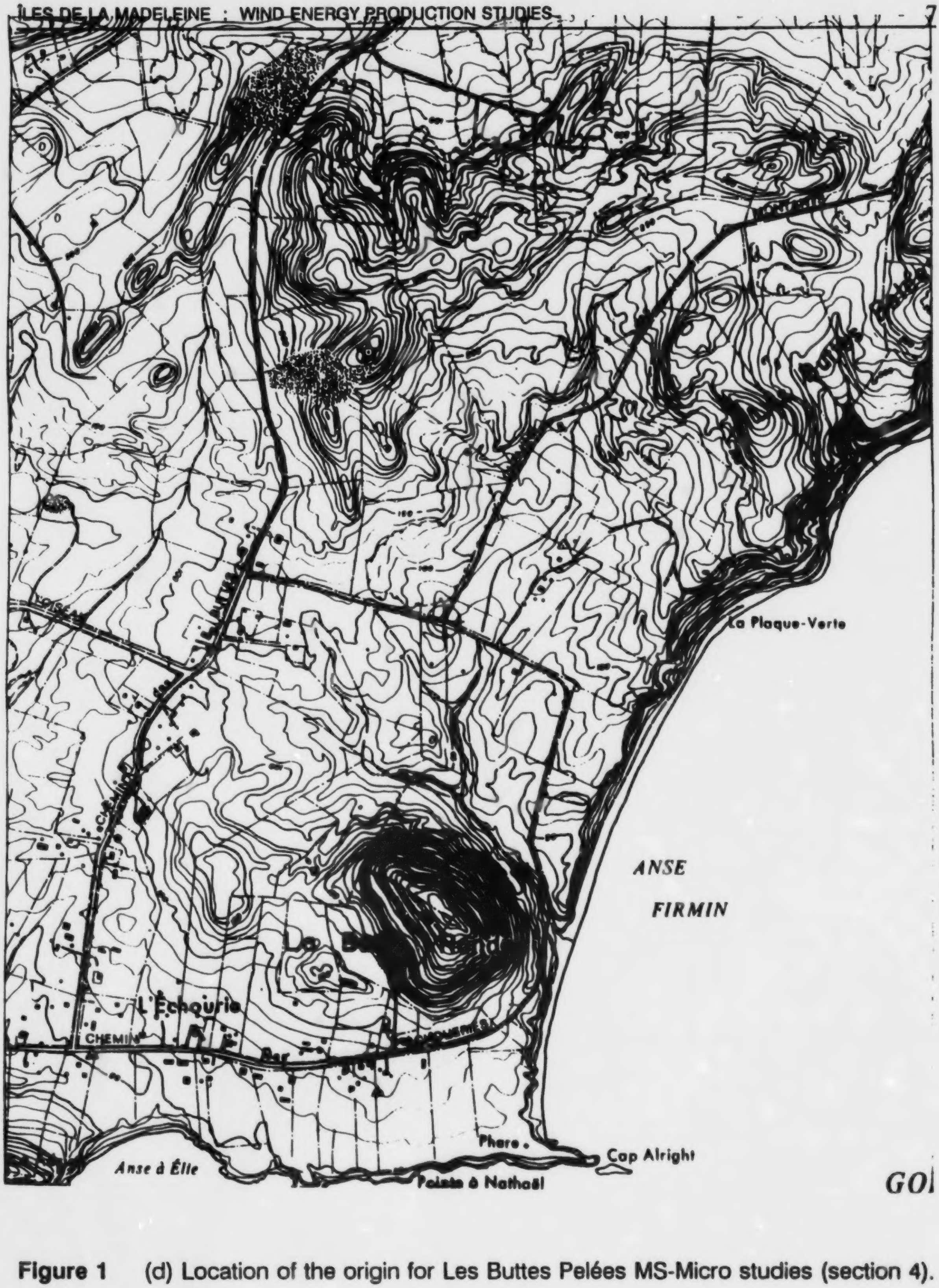

La Plaque-Verte
ANSE
FIRMIN
L'Échourie
CHEMIN
Phare
Cap Alright
Anse à Élle
Pointe à Nathaël
GOI

Figure 1 (d) Location of the origin for Les Buttes Pelées MS-Micro studies (section 4).

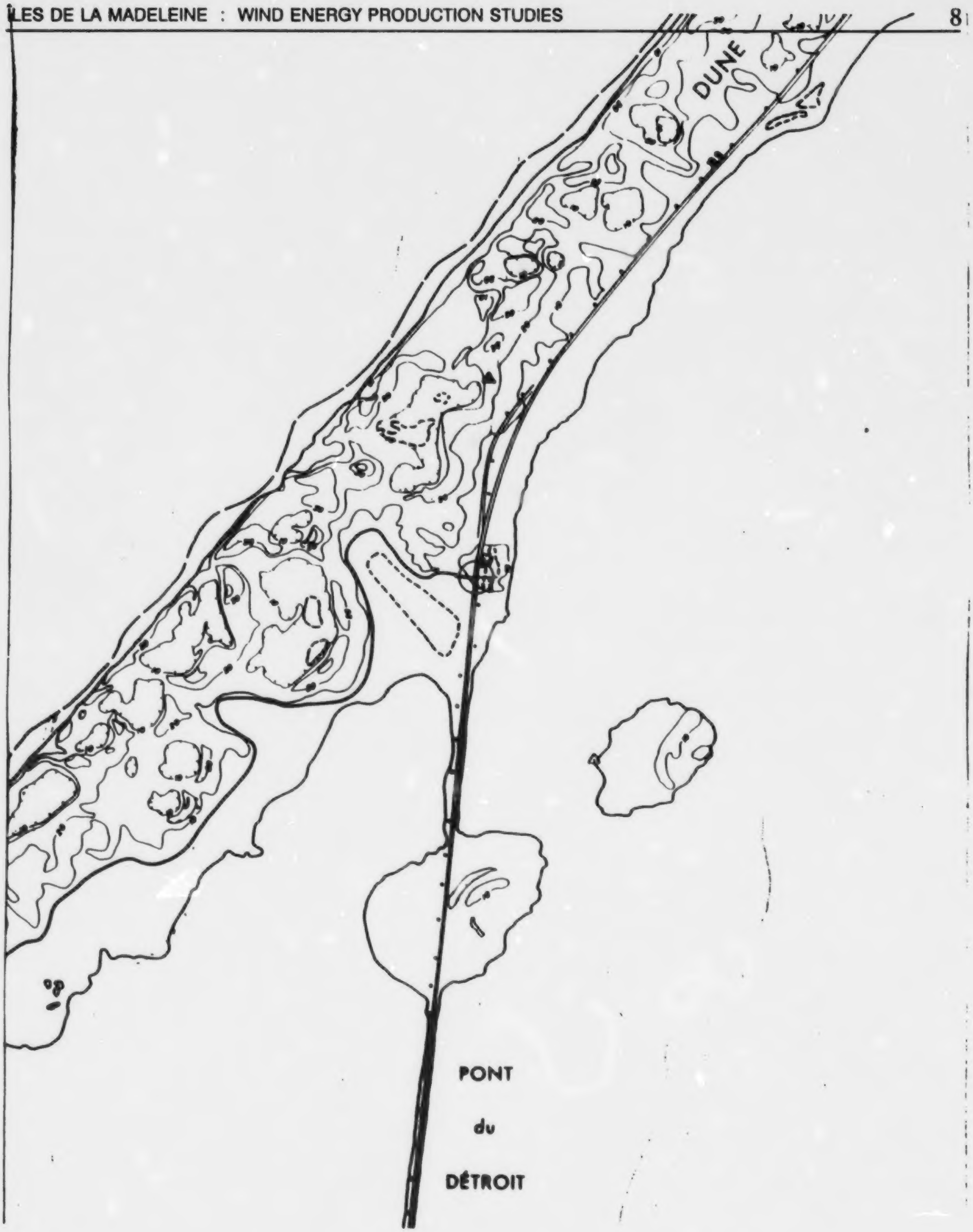

DUNE
PONT
du
DÉTROIT

Figure 1 (e) Location of the origin for La Dune du Nord.

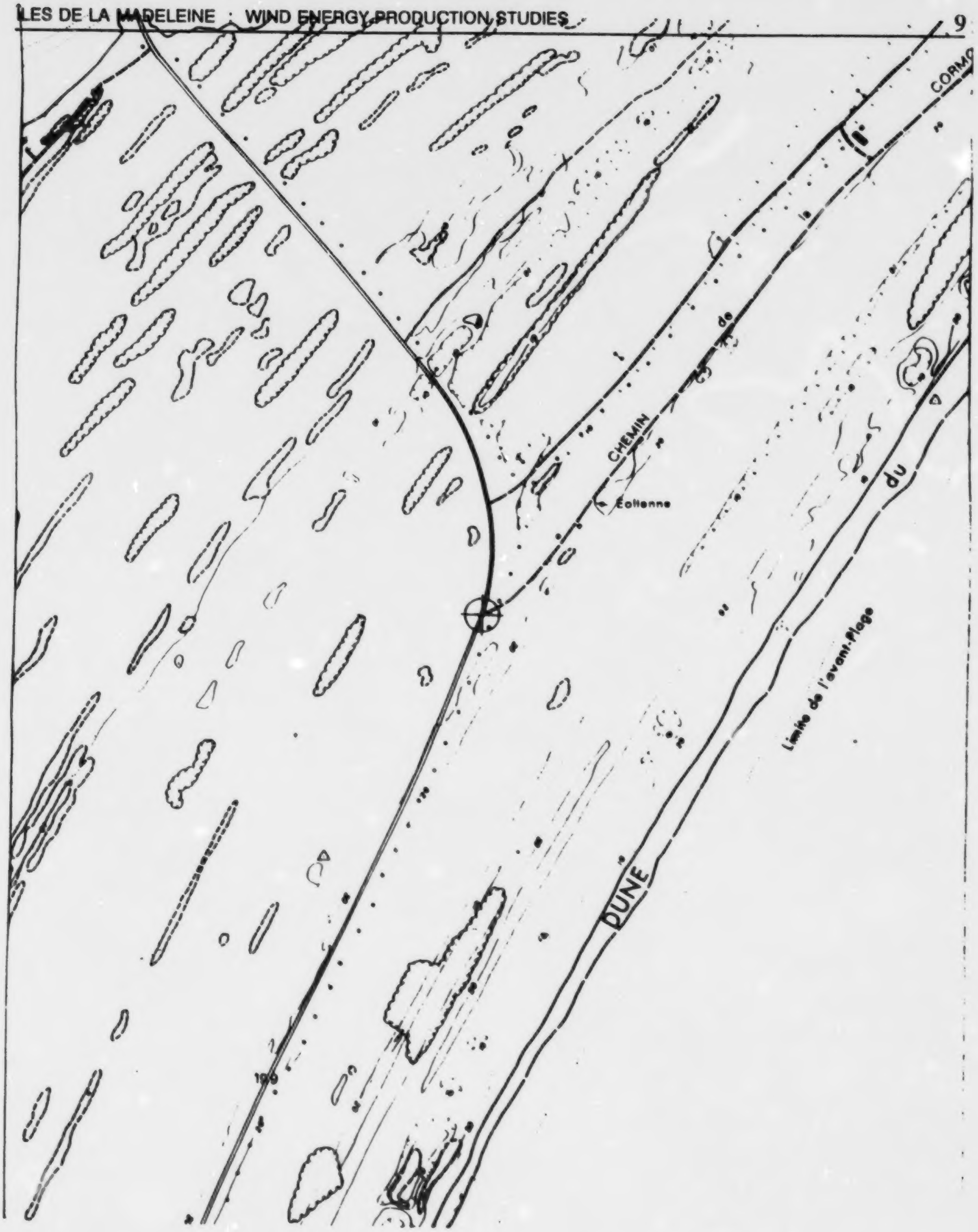

CORMO
CHEMIN
de
Éolienne
DUNE
du
Limite de l'avant-Plage
100

Figure 1 (f) Location of the origin for La dune du Sud.

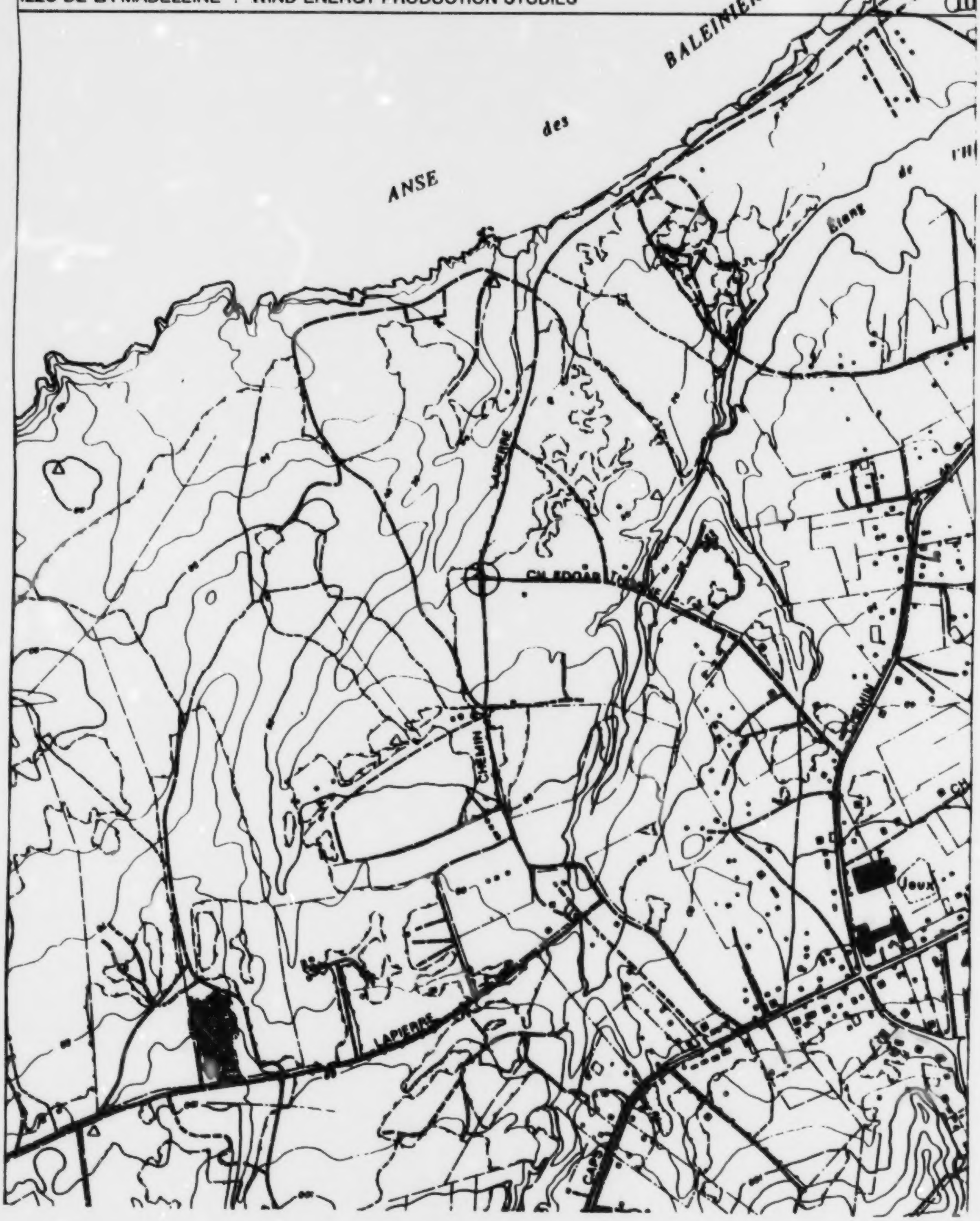

BALEINIE
des
ANSE
de
CH. EDGAR
LAPIERRE
CHEMIN
CHEMIN
LAPIERRE
CHEMIN
CAPS

Figure 1 (g) Location of the origin for Plateau des Caps.

Table 2 Wind speed vs. wind direction joint frequency table for Îles de la Madeleine Airport, 1983-1988. Entries are the number of observations in the six year period.

	DIRECTION (°) ±15°											
SPEED (m/s)	0	30	60	90	120	150	180	210	240	270	300	330
0.0-1.0	19	16	16	21	16	23	28	23	19	38	23	21
1.0-2.0	149	158	124	157	162	163	252	256	239	204	181	205
2.0-3.0	264	288	220	251	341	304	359	473	507	391	373	367
3.0-4.0	270	280	192	298	404	297	426	578	653	512	461	421
4.0-5.0	287	220	228	345	390	312	509	746	679	587	545	455
5.0-6.0	407	307	235	304	361	292	638	819	667	721	543	558
6.0-7.0	341	274	175	267	301	209	598	804	596	698	488	608
7.0-8.0	273	248	228	287	286	201	702	795	659	697	553	592
8.0-9.0	208	145	111	160	145	107	446	404	336	474	382	346
9.0-10.0	227	134	131	161	144	106	372	254	296	485	407	417
10.0-11.0	164	138	100	91	130	61	256	163	222	437	423	383
11.0-12.0	111	98	74	61	56	34	94	68	112	284	319	263
12.0-13.0	104	122	70	66	80	28	81	43	114	247	320	261
13.0-14.0	43	74	39	28	28	13	34	11	69	142	126	129
14.0-15.0	31	46	37	18	31	7	9	5	26	104	95	84
15.0-16.0	28	70	37	20	17	3	5	14	22	93	96	67
16.0-17.0	6	17	17	11	11	0	0	3	8	53	47	27
17.0-18.0	7	9	5	5	4	1	2	2	5	47	20	13
18.0-19.0	7	14	4	12	12	1	2	3	9	34	29	15
19.0-20.0	1	8	3	0	5	0	0	0	0	25	1	20
20.0-21.0	2	4	2	3	1	0	0	1	1	10	2	14
21.0-22.0	1	0	0	1	1	0	1	0	0	0	0	0

curves for the Bonus 450 turbine. The data supplied for this turbine stated that the wind speed was measured at 30m above ground level (a.g.l.) whereas the hub height of this machine is at 35m a.g.l. For the initial study, using WAsP, the wind speeds calculated at 30m were used for evaluation of the energy output. This corresponds to the curve labelled 'at 30m' in Figure 2. However, for the MS-Micro/2 study, in which it was desired (at Grosse Île) to use a displacement height to account for the forest at that location, it was decided to adjust the power curve by calculating the 35m wind speeds corresponding to the 30m wind speeds provided by the manufacturer. This was done with the assumptions of neutral atmospheric stability and a roughness length of 0.03m corresponding to a open agricultural land. This curve is labelled 'at hh=35m' in the figure.

Another characteristic of the turbines required by the program PARK was the thrust coefficient. PARK calculates the power reduction of individual turbines due to mutual interference effects when they are placed in closely spaced arrays. Unfortunately, it turned out to be difficult to obtain information on this characteristic for the turbines and it was necessary to use the "typical" thrust coefficient curve supplied with the program and graphed in Figure 3. A description of the model which serves as a basis for PARK suggests that the results are not very sensitive to the choice of the thrust coefficient. Note that in the MS-Micro/2 studies, this coefficient is not used.

2 THE WIND RESOURCE

The wind speed and direction for this region have been recorded at Grindstone Island from 1958 to 1980 and at the Îles de

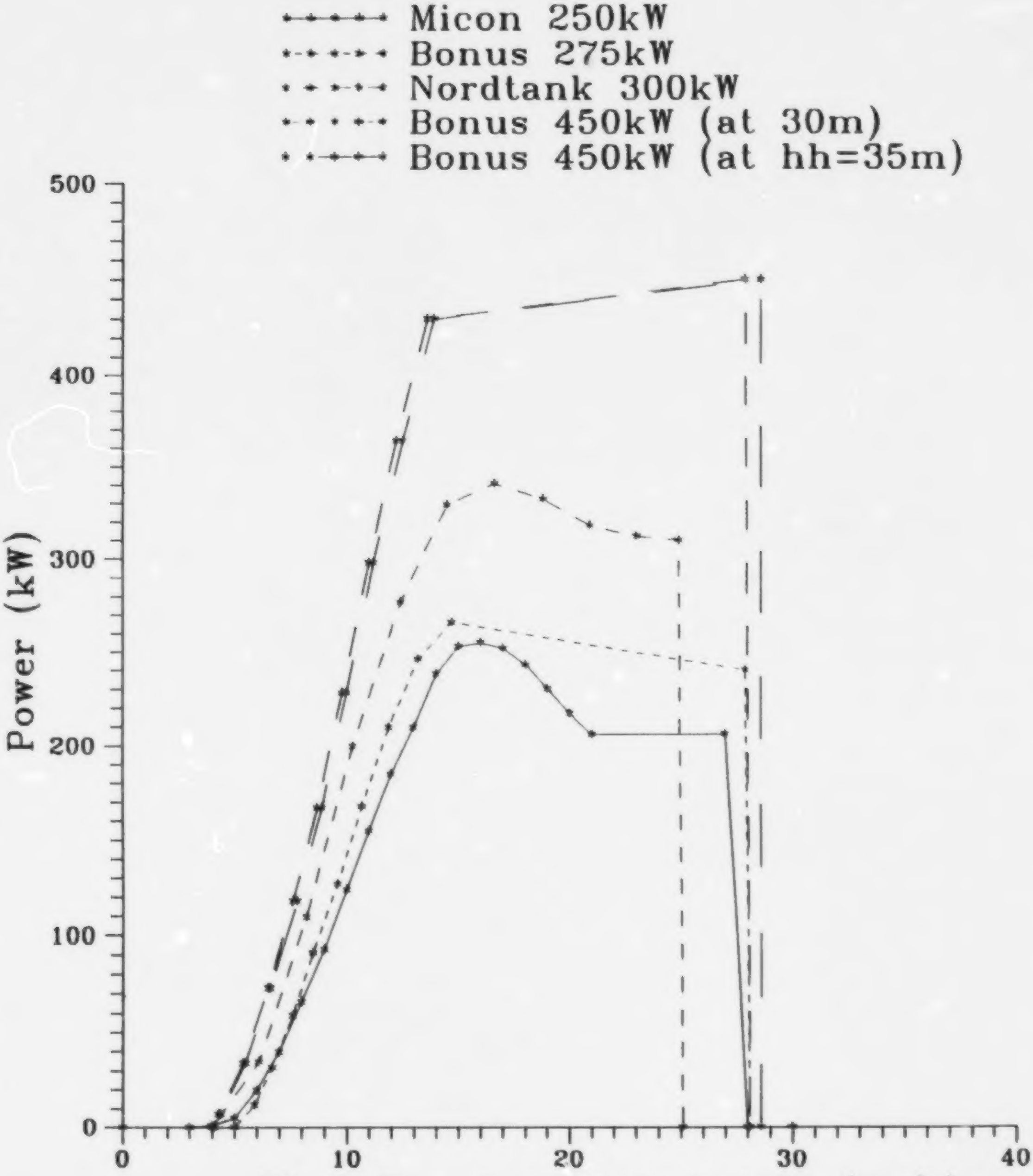


Figure 2 Power curves for the turbines studied.

la Madeleine Airport from 1980 to the present. However, it has only been recorded 24 hours per day in the past few years (*i.e.*, since the meteorological station was moved to the Airport location). Therefore, a joint-frequency table of wind speed *vs.* wind direction was compiled by the Canadian Climate Centre of the Atmospheric Environment Service for the six years 1983 to 1988 inclusive. This is reproduced in Table 2. Note that wind speed bins 1m/s in size and 12 direction bins of 30° have been used.

The data at the Airport anemometer are influenced by local obstacles, changes in surface roughness and variations in the topography. In order to use these data for consistent estimates of the wind at the potential turbine sites, it is necessary to remove these influences, *i.e.*, to determine a wind climatology appropriate to this region but not contaminated by effects local to the Airport. This was done with WAsP as follows.

Table 3 Surface roughness lengths.

No.	Description	z_o(m)
1	Ocean	0.0001
2	Open fields	0.03
3	Open fields with multiple houses, Dunes	0.1
4	Scrub	0.15
5	Forest	0.3

First, the topographic contours (WAsP refers to these as orography) surrounding the airport were digitized. (Note that this capability, in WAsP, is fairly primitive and that the digitization was actually done using MS-Micro/2 software with a subsequent conversion of the files to WAsP format.) Each contour line is represented by a large number of short line segments with its associated elevation. Second, the boundaries between areas of different aerodynamic roughness were digitized. In WAsP, a boundary is represented by a number of short line segments and has two associated numbers. One is the roughness type found to the "left" of the line when proceeding in the direction of digitization and the other is the roughness type found to the "right" of the line. (Note that an MS-Micro/2 program was modified to provide efficient digitization procedure.) The surface roughness lengths, z_o, chosen for the various terrain types in the region are listed in Table 3. A third step, which was not followed due to lack of data, would have been to enumerate and describe all of the obstacles in the vicinity of the Airport anemometer, *e.g.*, buildings, fuel tanks, rows of trees, *etc.* WAsP would have made adjustments to the anemometer data using its shelter model.

The WAsP program was then run using the digitized contours, the digitized roughness boundaries, the joint frequency table of observed wind speed *vs.* wind direction, the height of the airport anemometer (10m) and the location of the anemometer (assumed to be somewhere near the airport buildings) as input. The result of the calculation is a "wind atlas" which is a compilation of the wind regime which would exist at the anemometer location without the influences of the local topography and surface roughness. It is this wind atlas that summarizes the wind resource for the Îles de la Madeleine region. With the wind atlas compiled, it is then easy to use WAsP to estimate the wind speed at any other point in the region once its topographic and surface roughness characteristics are available to the program. These wind speeds are then used as

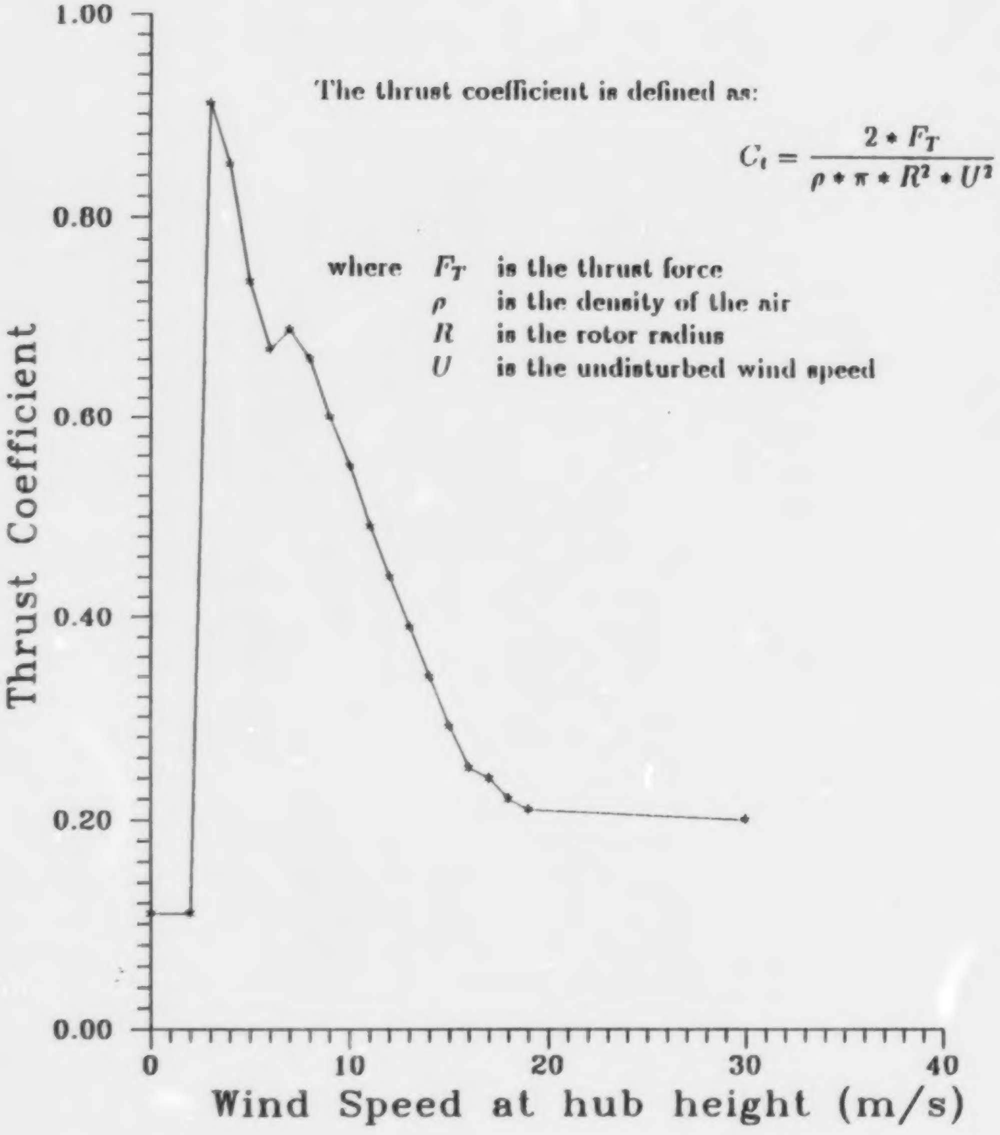


Figure 3 Typical thrust coefficient curve used by program PARK.

input for power calculations for the candidate turbines and sites.

Table 4a is the WAsP representation of the data of Table 2. It is actually a prediction of the wind data at the Airport anemometer itself, using the wind atlas as input. Table 4b represents the same data but with the topographic and surface roughness influences removed. Note that for these latter results, a uniform surface roughness of 0.0001 (ocean) has been assumed. In the table, the column headings have the following meanings:

Sect	Direction sector
Rch	Number of roughness changes in that sector
Input	Speed and direction corrections input directly by

Table 4 WAsP display of raw (observed) data and "wind atlas" data with effects of topography and roughness removed.

(a) Raw data, regenerated from "wind atlas".

```
Iles de le Madeleine Airport. 83-88                                28/ 1/91 23:29

+"I. DE LA MAD. AIRPORT-CENTRAL-FINE RESOL.","11-2  Height:    10.0 m a.g.l.

Sect  Rch      Input      Obstacle   Orography            A     k       %     E%

  0:   3    0.0%    0°     0.0%      0.5%    0°   :     7.4   1.96    6.3    6.6
 30:   2    0.0%    0°     0.0%     -0.3%    0°   :     7.4   1.73    5.7    6.7
 60:   2    0.0%    0°     0.0%      0.1%    0°   :     7.4   1.81    4.4    4.9
 90:   2    0.0%    0°     0.0%      0.4%    0°   :     6.9   1.85    5.4    4.7
120:   3    0.0%    0°     0.0%      0.8%    0°   :     6.5   1.72    6.0    4.9
150:   3    0.0%    0°     0.0%      1.0%    0°   :     6.1   1.91    4.8    2.8
180:   3    0.0%    0°     0.0%      0.2%    0°   :     7.1   2.58    9.8    7.1
210:   4    0.0%    0°     0.0%     -0.3%    0°   :     6.6   2.52   11.3    6.6
240:   3    0.0%    0°     0.0%      0.1%    0°   :     6.9   2.07   11.1    8.5
270:   3    0.0%    0°     0.0%      0.4%    0°   :     8.1   1.99   12.9   17.1
300:   5    0.0%    0°     0.0%      0.8%    0°   :     8.4   2.12   11.4   15.9
330:   3    0.0%    0°     0.0%      0.9%    0°   :     8.2   2.06   10.8   14.3

M=  6.5 m/s    E=  330. W/m²                            7.4   1.98
```

(b) With effects of topography and roughness removed; for z_o=0.0001m (ocean).

```
Iles de la Madeleine Airport. 83-88                                28/ 1/91 23:27

Default Site Description*                           Height:    10.0 m a.g.l.

Sect  Rch      Input      Obstacle   Orography            A     k       %     E%

  0:   0    0.0%    0°     0.0%      0.0%    0°   :     8.3   1.71    6.2    6.0
 30:   0    0.0%    0°     0.0%      0.0%    0°   :     9.7   1.71    5.6    8.4
 60:   0    0.0%    0°     0.0%      0.0%    0°   :     8.5   1.62    4.4    4.9
 90:   0    0.0%    0°     0.0%      0.0%    0°   :     7.7   1.61    5.4    4.6
120:   0    0.0%    0°     0.0%      0.0%    0°   :     7.9   1.52    6.0    6.0
150:   0    0.0%    0°     0.0%      0.0%    0°   :     6.7   1.63    4.7    2.5
180:   0    0.0%    0°     0.0%      0.0%    0°   :     8.3   2.19   10.1    7.3
210:   0    0.0%    0°     0.0%      0.0%    0°   :     8.0   2.12   11.5    7.6
240:   0    0.0%    0°     0.0%      0.0%    0°   :     8.0   1.77   11.1    9.1
270:   0    0.0%    0°     0.0%      0.0%    0°   :     9.9   1.99   13.0   17.6
300:   0    0.0%    0°     0.0%      0.0%    0°   :     9.4   1.88   11.3   13.7
330:   0    0.0%    0°     0.0%      0.0%    0°   :     9.1   1.82   10.7   12.3

M=  7.7 m/s    E=  593. W/m²                            8.6   1.79
```

	the user
Obstacle	Corrections due to obstacles
Orogra..	Speed and direction corrections due to the topographic influences
A	the Weibull A (or sometimes called C) coefficient
k	the Weibull k coefficient
%	the percentage of wind from that sector
E%	the percentage of wind energy from that sector.

Note also the following:

M	an average wind speed found by weighting over all sectors
E	kinetic energy of the wind at the stated height.

3 WAsP ANALYSIS OF FIVE SITES

3.1 INTRODUCTION

Combinations of five sites, four wind turbine types and three turbine configurations were analyzed using programs WAsP and PARK. Briefly, the procedure was as follows.

For each site, an easily identifiable origin for a local cartesian coordinate system was chosen - usually the junction of two roads (see Figure 1). The topographic contours and roughness boundaries were then digitized as described in Section 2. A suitable array of turbines was then chosen for the site and WAsP was run to calculate the hub height wind resource for each location of the turbine array. Regional meteorological data were extracted automatically by WAsP from the wind atlas described in Section 2. The derived wind data were then passed to program PARK which calculated the annual energy output of the turbine array, taking into account the effects of interactions between the turbines.

Three different types of arrays, designated A, B and C, were considered at each site (see Appendix B for examples). An array of type A was a single line of turbines, oriented with its axis as nearly perpendicular to the prevailing wind (from the northwest) as possible. This would minimize turbine wake interaction (*i.e.*, power reduction) for the wind direction containing the largest portion of the available energy. The turbines were usually placed with the minimum spacing (four rotor diameters) which can be handled by program PARK.

Arrays of type B were designed with much the same constraints as those of type A except that two lines of turbines, one behind the other and staggered, were placed as close to perpendicular to the prevailing wind direction as possible. Type C arrays were made up of three lines of turbines.

Note that not all types of array were possible at all sites because of terrain constraints.

The number of turbines in any of the arrays was chosen so that there would be a nominal 5MW of installed power, *i.e.*, 20 for the Micon 250kW, 18 for the Bonus 275kW, 17 for the Nordtank 300kW and 11 for the Bonus 450kW.

3.2 PROGRAM PARK

Program PARK calculates the individual and total output from "windparks" - arrays of turbines with spacing sufficiently close for the turbine wakes to interact with other turbines in the array, resulting in a reduction of the total energy produced by the windpark. For input, PARK requires 1) the locations of the turbines, 2) the wind resource at hub height at the turbine locations (or for the area in general) represented as frequencies, Weibull A's and Weibull k's for each of the (12) direction sectors, 3) the turbine power curve at hub height, 4) the thrust coefficient curve for the turbine (Section 1.4), 5) the hub height, 6) the rotor radius, 7) a wake decay constant and 8) an air density correction for altitude and temperature.

The turbine locations were specified as described in Section 3.1. The wind resources were calculated by WAsP as described above. The turbine power curves were supplied as shown in Figure 2. These files also included hub height and rotor radius data. A typical thrust coefficient curve (Figure 3) was used for all of the turbines. As suggested in the PARK manual, wake decay constants ranging between 0.03 and 0.05 were used, corresponding to turbulence intensity over water. Note that the incident wind is over water at most of the sites. No correction was made to the air density since the sites are essentially at sea level and the yearly average temperature in the Îles de la Madeleine (4.6C) is reasonably close (in terms of absolute temperature) to the standard temperature (15C).

3.3 RESULTS

The detailed data pertaining to individual runs (*i.e.*, a particular array type with a particular turbine type at a particular site) are collated in Appendix B. These data are summarized in Tables 5a to 5c which list the predicted annual energy productions in GWh/yr along with the array efficiencies. Note that not all array types were possible at all locations.

It is interesting to note that for a nominal 5MW of installed power, the Nordtank 300kW wind turbine produces significantly more energy than the other turbine at all locations and for all array configurations. Examination of Figure 2 suggests that this turbine should be given a higher nominal rating.

Configuration A results in the greatest output at all sites while amongst the sites, Grosse Île accounts for the largest estimated output.

It is also noteworthy that the array efficiencies tend to be quite high in all cases with a worst value of 90% and a high of 98%. Note that efficiency is never defined in the PARK manual but it is reasonable to assume that it is the ratio of the energy generated when turbine interactions are taken into account and the energy generated for a hypothetical case when turbines do not cause mutual reductions of each other's energy output.

N.B. During the optimization study described in the next section, 'bugs' were found in the WAsP program which resulted in incorrect values of the Weibull coefficients being passed to the PARK program. It is conceivable that such errors also occurred during the calculations summarized in Table 5. However, experience with the program suggests that the errors will not contribute substantially to the overall results summarized in that table. It is unlikely that any errors which may have occurred would result in any differences in the rankings of the machines and sites. As

Table 5 Predicted annual energy production (GWh/yr) for three array types, five sites and four wind turbine choices. Efficiencies are shown in brackets.

(a) Array type A, single line.

	Micon 250kW (20 turbines)	Bonus 275kW (18 turbines)	Nordtank 300kW (17 turbines)	Bonus 450kW (11 turbines)
Grosse Île	N/A	N/A	N/A	19.73 (0.98)
La Dune du Nord	15.93 (0.96)	15.73 (0.96)	19.63 (0.96)	16.99 (0.96)
La Dune du Sud - A	N/A	N/A	N/A	N/A
Les Buttes Pelées	N/A	N/A	N/A	N/A
Plateau des Caps	14.02 (0.97)	13.65 (0.96)	17.42 (0.96)	14.75 (0.96)

(b) Array type B, two lines.

	Micon 250kW (20 turbines)	Bonus 275kW (18 turbines)	Nordtank 300kW (17 turbines)	Bonus 450kW (11 turbines)
Grosse Île	18.08 (0.97)	18.14 (0.97)	21.53 (0.96)	18.09 (0.96)
La Dune du Nord	15.47 (0.93)	15.27 (0.93)	19.14 (0.93)	16.65 (0.94)
La Dune du Sud - A	14.06 (0.96)	14.47 (0.96)	17.44 (0.95)	14.79 (0.95)
Les Buttes Pelées	14.36 (0.94)	14.31 (0.94)	17.55 (0.93)	15.23 (0.94)
Plateau des Caps	13.32 (0.93)	13.17 (0.93)	16.61 (0.93)	14.50 (0.94)

(c) Array type C, three lines.

	Micon 250kW (20 turbines)	Bonus 275kW (18 turbines)	Nordtank 300kW (17 turbines)	Bonus 450kW (11 turbines)
Grosse Île	17.29 (0.96)	17.02 (0.95)	21.04 (0.94)	17.54 (0.94)
La Dune du Nord	15.06 (0.91)	14.81 (0.90)	18.55 (0.91)	N/A
La Dune du Sud - A	13.86 (0.96)	13.61 (0.95)	17.16 (0.94)	14.79 (0.95)
Les Buttes Pelées	13.33 (0.92)	13.21 (0.92)	16.10 (0.92)	12.96 (0.93)
Plateau des Caps	13.01 (0.91)	12.77 (0.91)	16.31 (0.92)	14.19 (0.94)

a result, it was decided not to attempt a recalculation since this would entail a considerable investment of time. The program developers have been informed of the problem.

4 OPTIMIZATION STUDY

4.1 INTRODUCTION

This portion of the report describes an optimization study for two of the candidate wind turbines (Bonus 450kW and Nordtank 300kW) at two of the sites (Grosse Île and Les Buttes Pelées). The object was to find an optimum distribution of turbines that would maximize the energy output for the site under consideration. This was to be done for a variable number of turbines (7 to 11 for the Bonus 450kW and 11-17 for the Nordtank 300kW) so that the production *vs.* number-of-turbines and incremental increase characteristics of the sites and turbines could be examined. A further point of consideration was the modelling of the influence of the 6m trees covering the Grosse Île site.

Originally, it had been planned to use WAsP to carry out this study, although its characteristic of treating only single points meant that it would be cumbersome for these calculations. A large amount of analysis was performed with WAsP only to discover that a bug in the program rendered the results highly suspect. Thereafter, a decision was made to add to the capabilities of MS-Micro/2 so that it could perform the optimizations required. (Conceptually, it is more suitable for this type of investigation since it produces data on a grid covering the site under study.)

4.2 MS-Micro/2

MS-Micro/2 is fully described in Walmsley and Salmon (1989).

Briefly, the model is used to predict the three-dimensional modifications to wind flow by the topography and surface roughness of real terrain. There are some restrictions which govern the accurate application of the model. These are worth re-iterating here, so that the results to be presented on the following pages can be viewed in the appropriate context.

(1) The boundary layer is assumed to be neutrally stable.

(2) The terrain slopes are less than about one in four.

(3) The terrain being modelled is not so extensive that synoptic variability must be considered. The model assumes a homogeneous, well-developed incident wind profile. It also assumes that Coriolis effects are negligible.

(4) The prediction levels are not so high that they are above the atmospheric boundary layer nor are they so low that they are near the roughness element height.

(5) It must be possible to represent the region as an area of complex topography and aerodynamic roughness surrounded by a flat, homogeneous plain.

4.3 PROCEDURE AND PARAMETERS

For the analyses, domains of 4,000m x 4,000m (Grosse Île) and 8,000m x 8,000m (Les Buttes Pelées) centred on their respective origins (shown in Figures 1b and 1d) were chosen.

For Grosse Île, the WAsP topography files were converted to MS-Micro/2 format while for Les Buttes Pelées the topography

Table 6 MS-Micro/2 model parameters; Grosse Île, Bonus 450kW.

```
Project Name:  MD - Grosse Ile  91/01/20  12:46
------
     256          No. of X grid lines
     256          No. of Y grid lines
   -2000.         Left boundary of domain (m)
    2000.         Right boundary of domain (m)
   -2000.         Lower boundary of domain (m)
    2000.         Upper boundary of domain (m)
------
     12   No. of directions
Dir.No. / Dir.(deg) / Outer level (m) / Upstream
rough. class / Frequency (%) / Weibull C /
Weibull k
 1    000    0.     1       6.2      9.7     1.92
 2    030    0.     1       5.6     11.1     1.84
 3    060    0.     1       4.4      9.9     1.79
 4    090    0.     1       5.4      9.1     1.82
 5    120    0.     1       6.0      9.2     1.69
 6    150    0.     1       4.7      8.1     1.92
 7    180    0.     1      10.1      9.9     2.58
 8    210    0.     1      11.5      9.5     2.50
 9    240    0.     1      11.1      9.5     2.03
10    270    0.     1      13.0     11.4     2.18
11    300    0.     1      11.3     10.8     2.08
12    330    0.     1      10.7     10.5     2.01
------
MOGR1.TCN         Topography contour file
MOGR12.RBS        Roughness boundary file
------
      5   No. of roughness classes
Class.No. / Roughness (m) / Description
   1  1.00E-04        Ocean
   2  3.00E-02        Fields
   3  1.00E-01        Houses
   4  1.50E-01        Scrub
   5  3.00E-01        Forest
------
     0.           Origin x-shift (m)
     0.           Origin y-shift (m)
   1250.          Inner matching distance (m)
   1750.          Outer matching distance (m)
------
      1   No. of delta-z levels
Level No. / Level (m)
   1     31.00
```

was re-digitized as described in the MS-Micro/2 manual. 'Master topographic grids' were computed and were used for subsequently required direction-dependent grids. The original digitized contours are shown (unlabelled) in Figures 4 and 8 with full domains. Note that there are extra zero contours around the shoreline at both sites. These have been added to define the ocean level surrounding the land masses. Figures 5 and 9 show sample gridded representations of the topography as input into the numerical model.

The boundaries surrounding the regions of different surface roughnesses were also re-digitized. Five roughness area types were chosen as described in Table 2. The original digitized roughness area boundaries are shown in Figures 6 and 10. The 'seed points' are also visible. Figures 7 and 11 show representations of typical gridded roughness fields for the inner portion of the domain.

Tables 6 (Grosse Île, Bonus), 7 (Grosse Île, Nordtank), 8 (Les Buttes Pelées, Bonus) and 9 (Les Buttes Pelées, Nordtank), which are output from program MSPAR of the MS-Micro/2 system, list the parameters chosen for the modelling exercise. Maximum horizontal resolutions of 256x256 grid lines were superimposed on the model domains centred on their respective origins resulting in model resolutions of 15.6 and 31.3m for Grosse Île and Les Buttes Pelées respectively.

Twelve wind directions were chosen for analysis so that the previously determined WAsP wind atlas data could be used in this part of the study. For each direction, a number of parameters have been assigned. The 'Outer Level' is the elevation at the boundary of the computational domain in the direction of the incident wind under consideration. It is chosen to avoid any abrupt topographic changes upstream of the area under scrutiny. For this analysis, 0.0m (ocean level) was assigned for all directions. The 'Upstream roughness class' has been chosen as 1 (open ocean) for all directions. The 'Relative frequency' is the frequency of wind from the direction being considered. Percentage frequencies are shown in the table. 'Weibull C' and 'Weibull k' are the Weibull parameters corresponding to the wind distribution for the direction being considered. Note that the Weibull C parameter here is identical to the Weibull A parameter of WAsP. The frequencies and Weibull parameters have been determined using WAsP. Note that they will depend on the height (see 'Level' below) being considered which will correspond to the hub height (or hub height minus displacement height) of the turbine under consideration.

M0GRI.TCN and M0GRI2.RBS are the names of the topographic contour and roughness boundary/seed files respectively for Grosse Île while M0LBP3.TCN AND M0LBP3.RBS correspond to Les Buttes Pelées.

The number of roughness classes was chosen to correspond to the five terrain types listed in Table 2.

No origin shifts were applied to the topography and roughness fields.

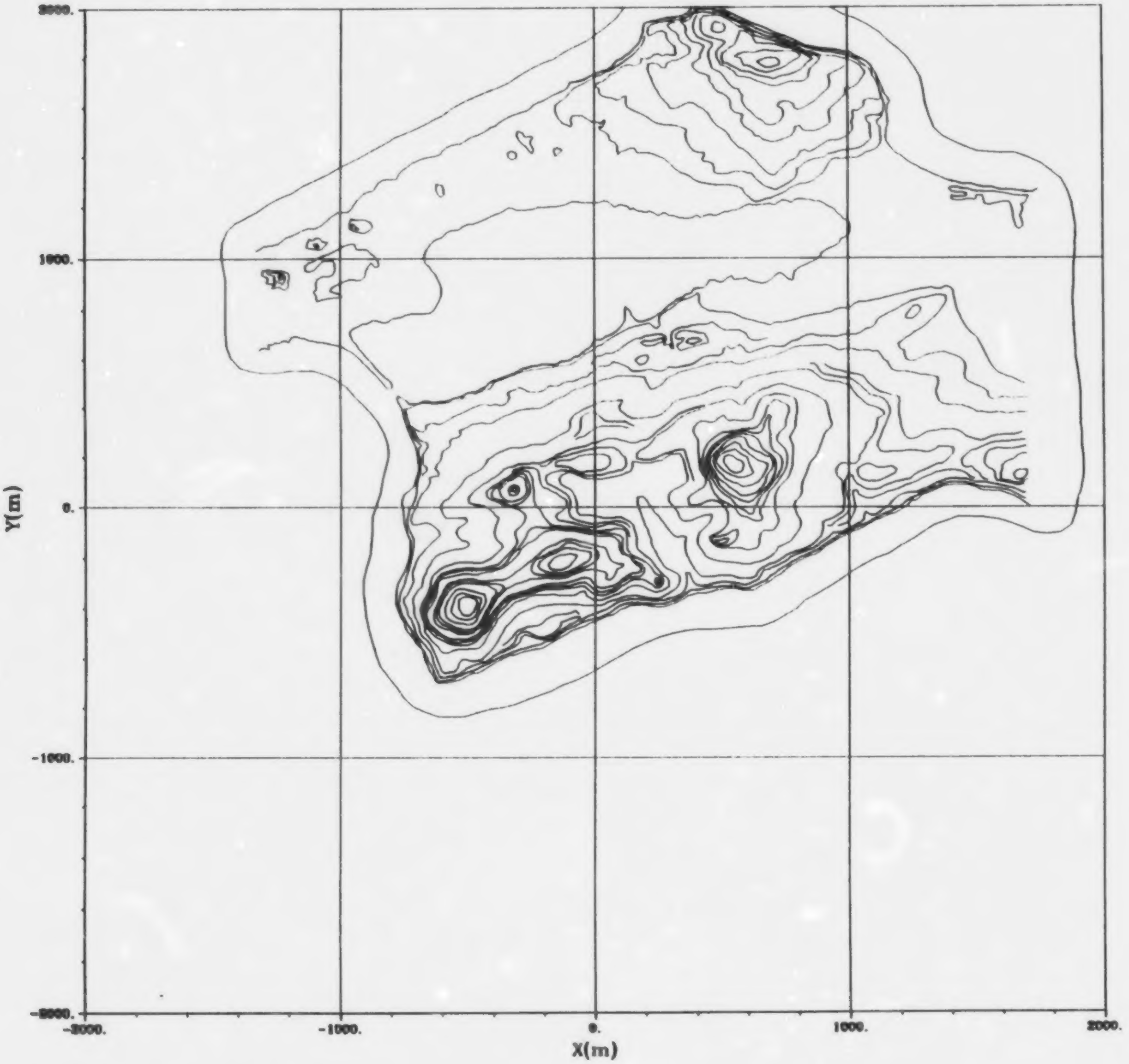
The 'Inner matching distance' and 'Outer matching distance' define three (square) regions surrounding the origin. Within the inner matching distance, the topographic grid represents the actual topography as accurately as possible. Outside of the outer matching distance the topography is flat with its level equal to the value defined under 'Outer level'. Note that this vertical level can be direction dependent. Between the inner matching and outer matching distances, the topography is 'blended' to smoothly match inner and outer regions to each other. Also, the surface roughness everywhere outside of the outer matching distance is set to the 'Upstream roughness class'.

Table 7 MS-Micro/2 parameter summary; Grosse Île, Nordtank 300kW.

```
Project:  M0 - Grosse Ile  91/01/18  14:58

------
     256          No. of X grid lines
     256          No. of Y grid lines
   -2000.         Left boundary of domain (m)
    2000.         Right boundary of domain (m)
   -2000.         Lower boundary of domain (m)
    2000.         Upper boundary of domain (m)
------
      12   No. of directions
Dir.No. / Dir.(deg) / Outer level (m) / Upstream
 rough. class / Frequency (%) / Weibull C /
 Weibull k
 1    000    0.    1     6.2     9.5    1.88
 2    030    0.    1     5.6    10.9    1.81
 3    060    0.    1     4.4     9.7    1.75
 4    090    0.    1     5.4     8.9    1.78
 5    120    0.    1     6.0     9.0    1.65
 6    150    0.    1     4.7     7.8    1.88
 7    180    0.    1    10.1     9.6    2.52
 8    210    0.    1    11.5     9.3    2.44
 9    240    0.    1    11.1     9.2    1.98
10    270    0.    1    13.0    11.2    2.14
11    300    0.    1    11.3    10.6    2.04
12    330    0.    1    10.7    10.3    1.97
------
M0GRI.TCN         Topography contour file
M0GRI2.RBS        Roughness boundary file
------
       5   No. of roughness classes
Class.No. / Roughness (m) / Description
   1  1.00E-04      Ocean
   2  3.00E-02      Fields
   3  1.00E-01      Houses
   4  1.50E-01      Scrub
   5  3.00E-01      Forest
------
      0.          Origin x-shift (m)
      0.          Origin y-shift (m)
   1250.          Inner matching distance (m)
   1750.          Outer matching distance (m)
------
       1   No. of delta-z levels
Level No. / Level (m)
   1    27.00
```

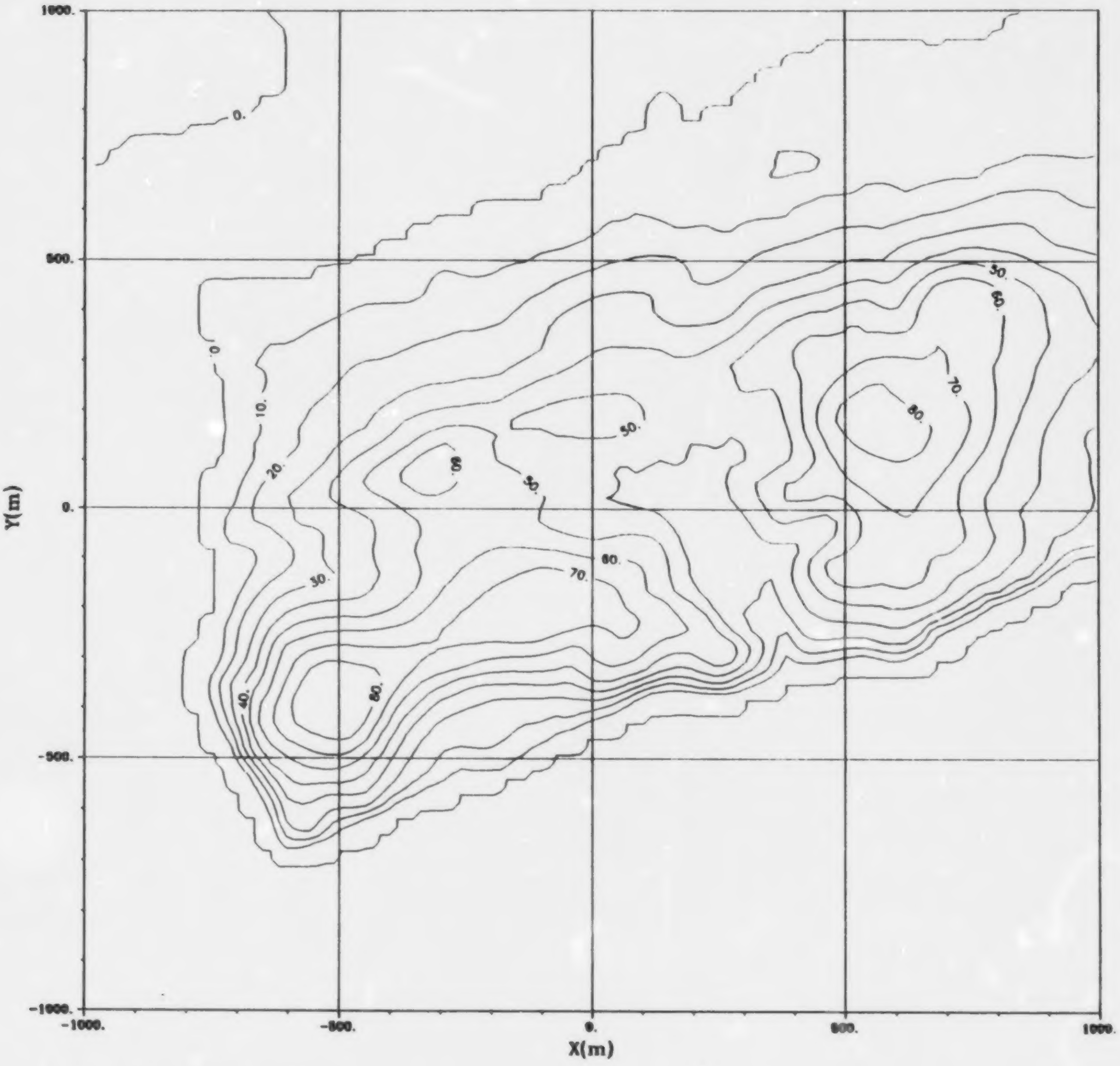
For this study, only two vertical prediction levels (delta-z levels), corresponding to the hub heights of the wind turbines, were chosen for each site. At Grosse Île, heights of 31m for the Bonus 450kW and 27m for the Nordtank 300kW corresponded to the hub height minus the displacement height due to the 6m trees (4m). At Les Buttes Pelées where the ground is open, heights of 35m and 31m were chosen respectively. Choice of the displacement height will be discussed below. Note that delta-z is measured as


2000.
1000.
0.
-1000.
-2000.
Y(m)
-2000.
-1000.
0.
1000.
2000.
X(m)

TOPOGRAPHY INPUT

M0 - Grosse Ile 91/01/20 12:46

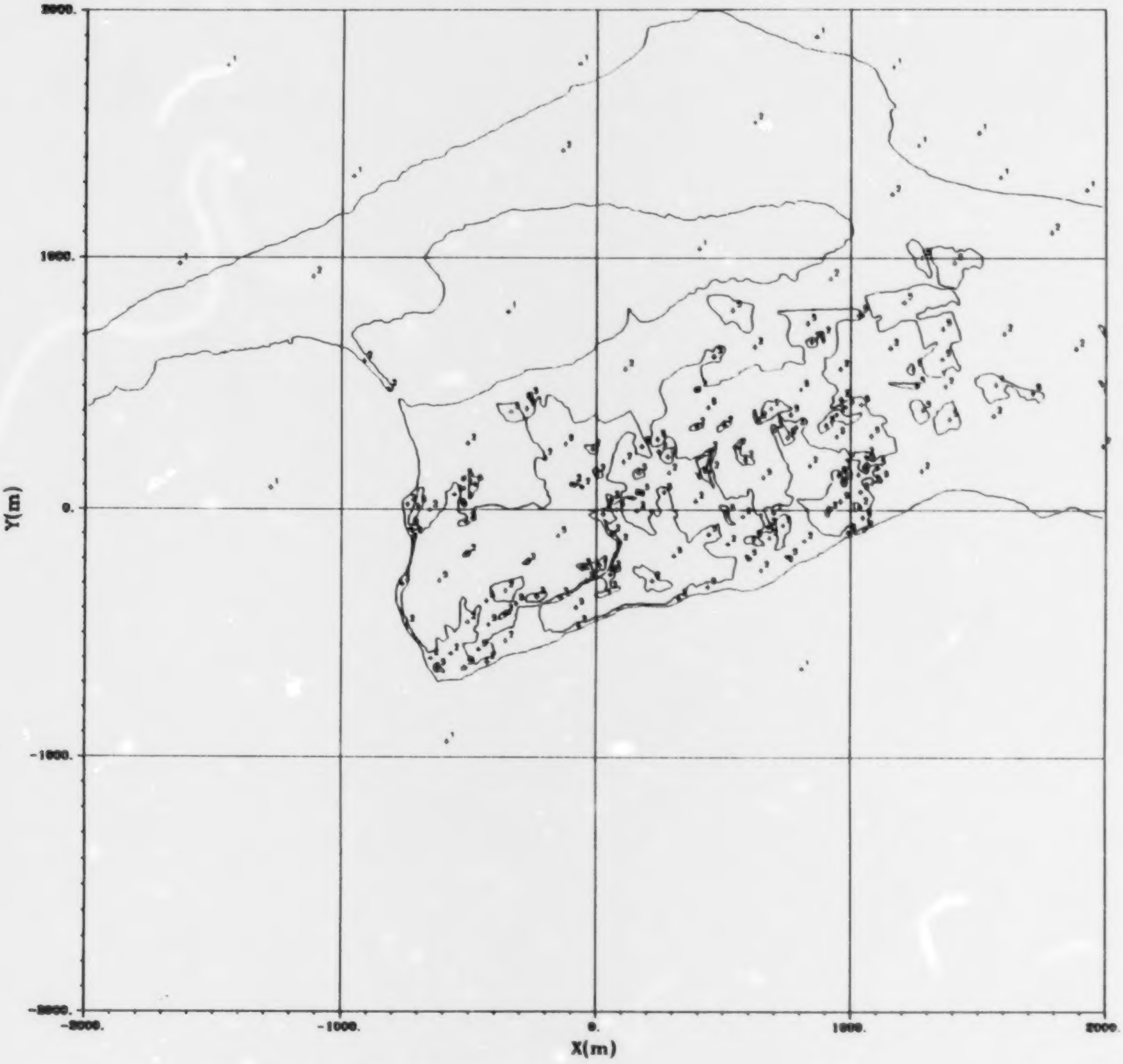
Figure 4 Digitized contours for Grosse Île.


1000.
500.
0.
-500.
-1000.
Y(m)
-1000.
-500.
0.
500.
1000.
X(m)
0.
0.
10.
20.
30.
40.
50.
50.
50.
60.
60.
60.
70.
70.
80.
80.
80.
50.
60.

GRIDDED TOPOGRAPHY (m)

M0 - Grosse Ile 91/01/20 12:46

Figure 5 Contours of gridded topography for Grosse Île.


2000.
1000.
0.
-1000.
-2000.
Y(m)
-2000.
-1000.
0.
1000.
2000.
X(m)

ROUGHNESS BOUNDARIES AND SEEDS

M0 - Grosse Ile 91/01/20 12:46

Figure 6 Digitized roughness boundaries and seeds for Grosse Île.

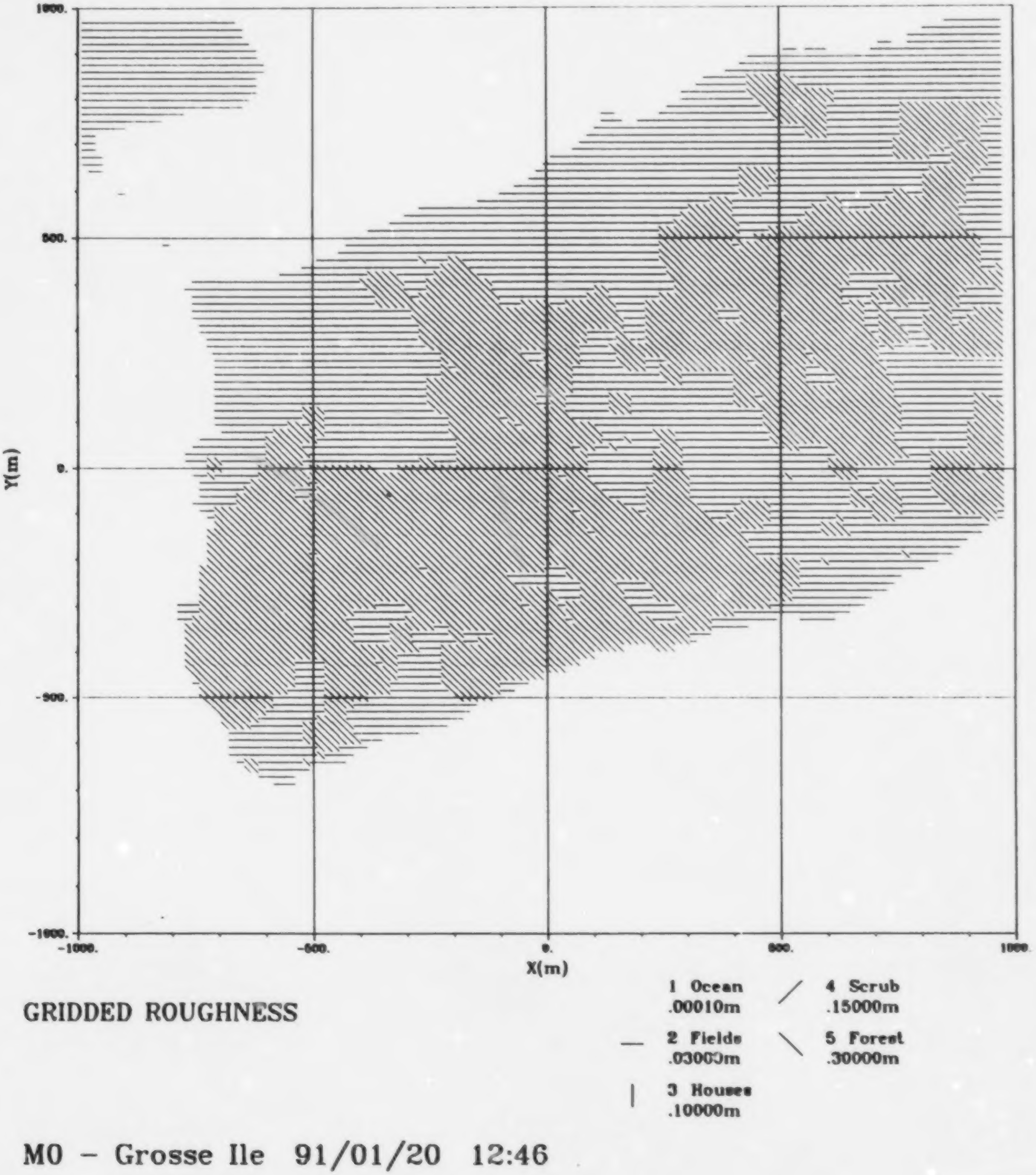
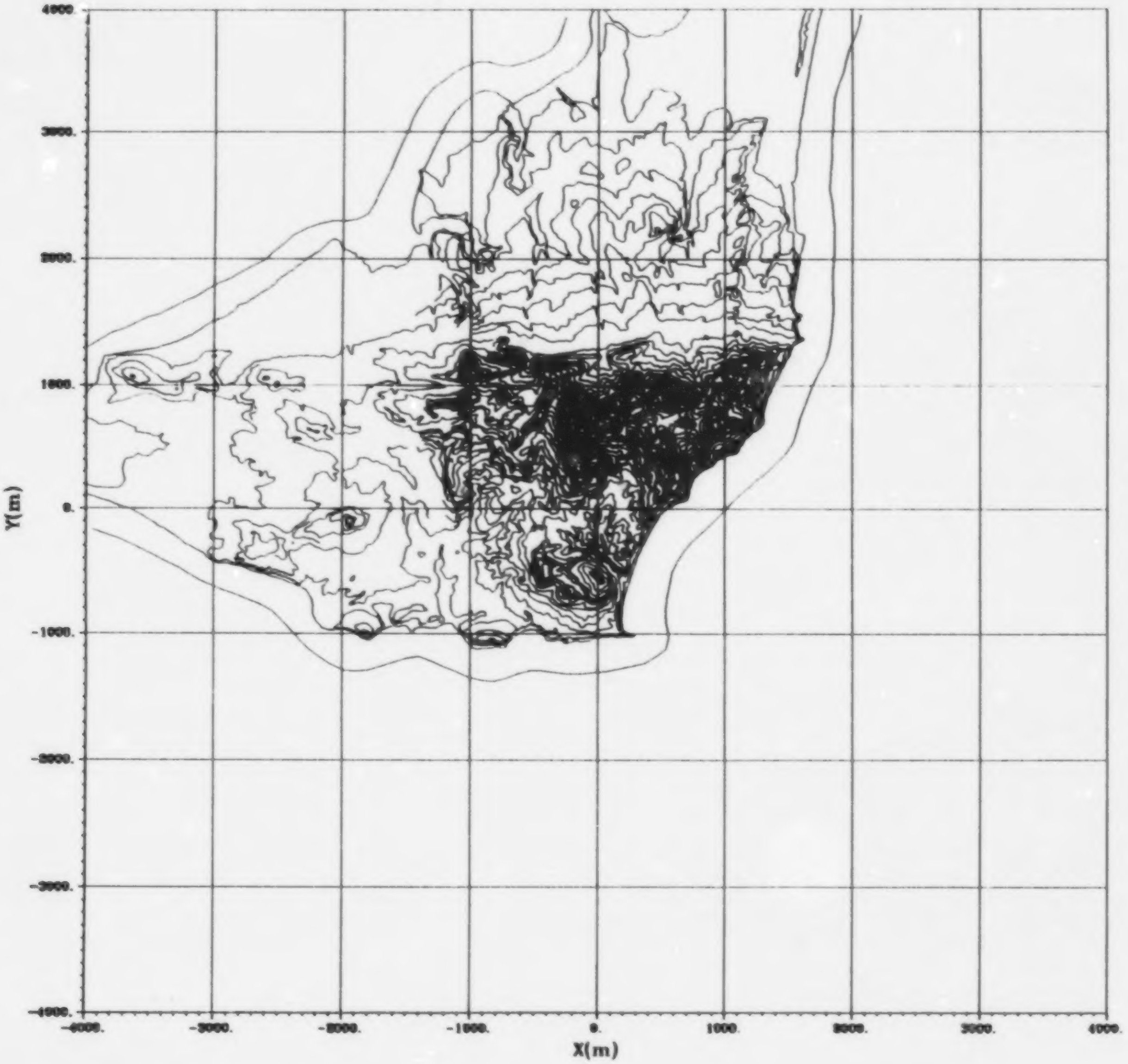

1000.
500.
0.
-500.
-1000.
Y(m)
-1000.
-500.
0.
500.
1000.
X(m)
GRIDDED ROUGHNESS
1 Ocean .00010m
— 2 Fields .03000m
| 3 Houses .10000m
/ 4 Scrub .15000m
\ 5 Forest .30000m
M0 - Grosse Ile 91/01/20 12:46

Figure 7 Representation of gridded roughness for Grosse Île.


4000.
3000.
2000.
1000.
0.
-1000.
-2000.
-3000.
-4000.
Y(m)
-4000.
-3000.
-2000.
-1000.
0.
1000.
2000.
3000.
4000.
X(m)

TOPOGRAPHY INPUT

M0 – Les Buttes Pelees 91/01/24 12:07

Figure 8 Digitized topography contours for Les Butte Pelées.

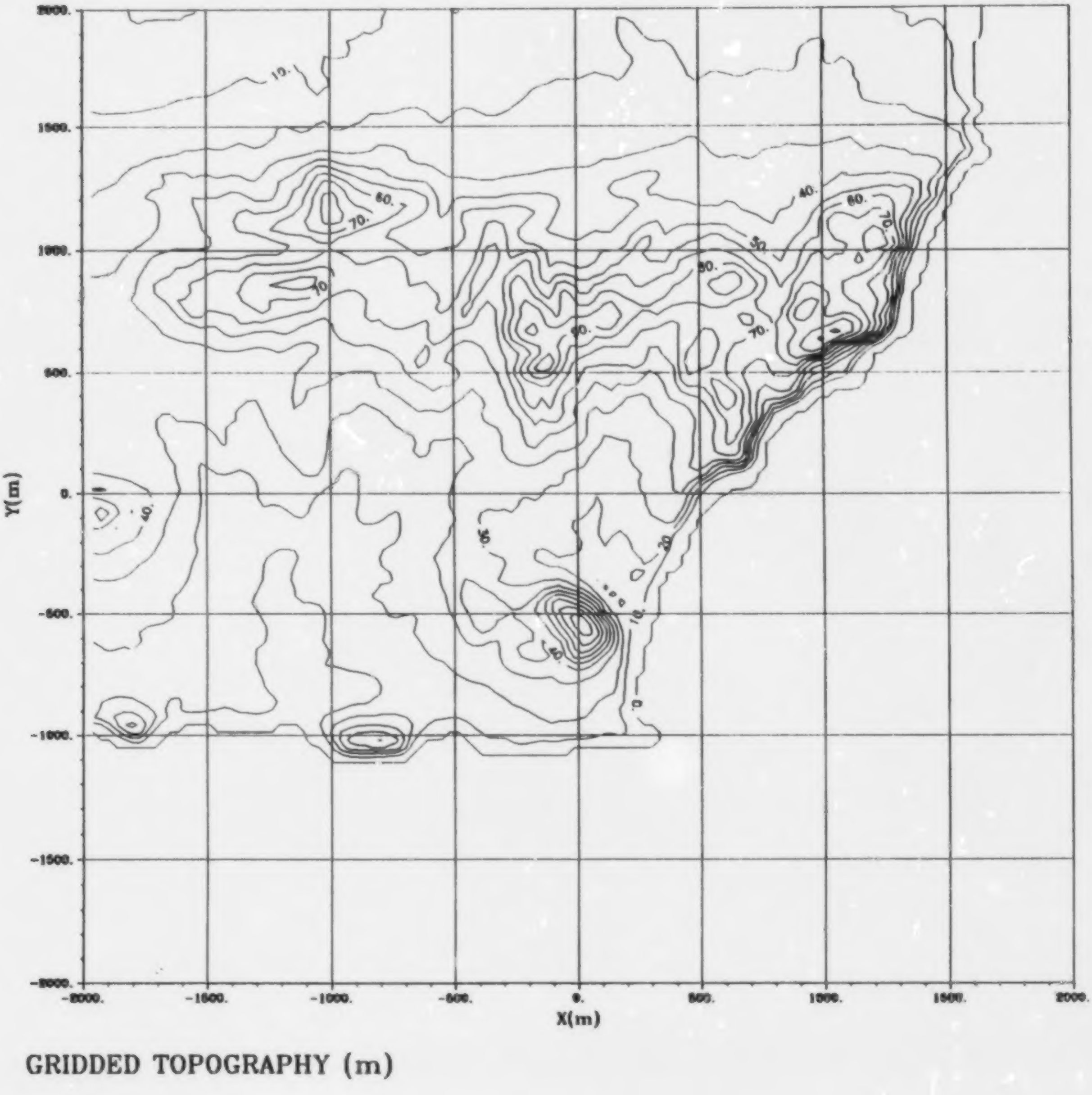
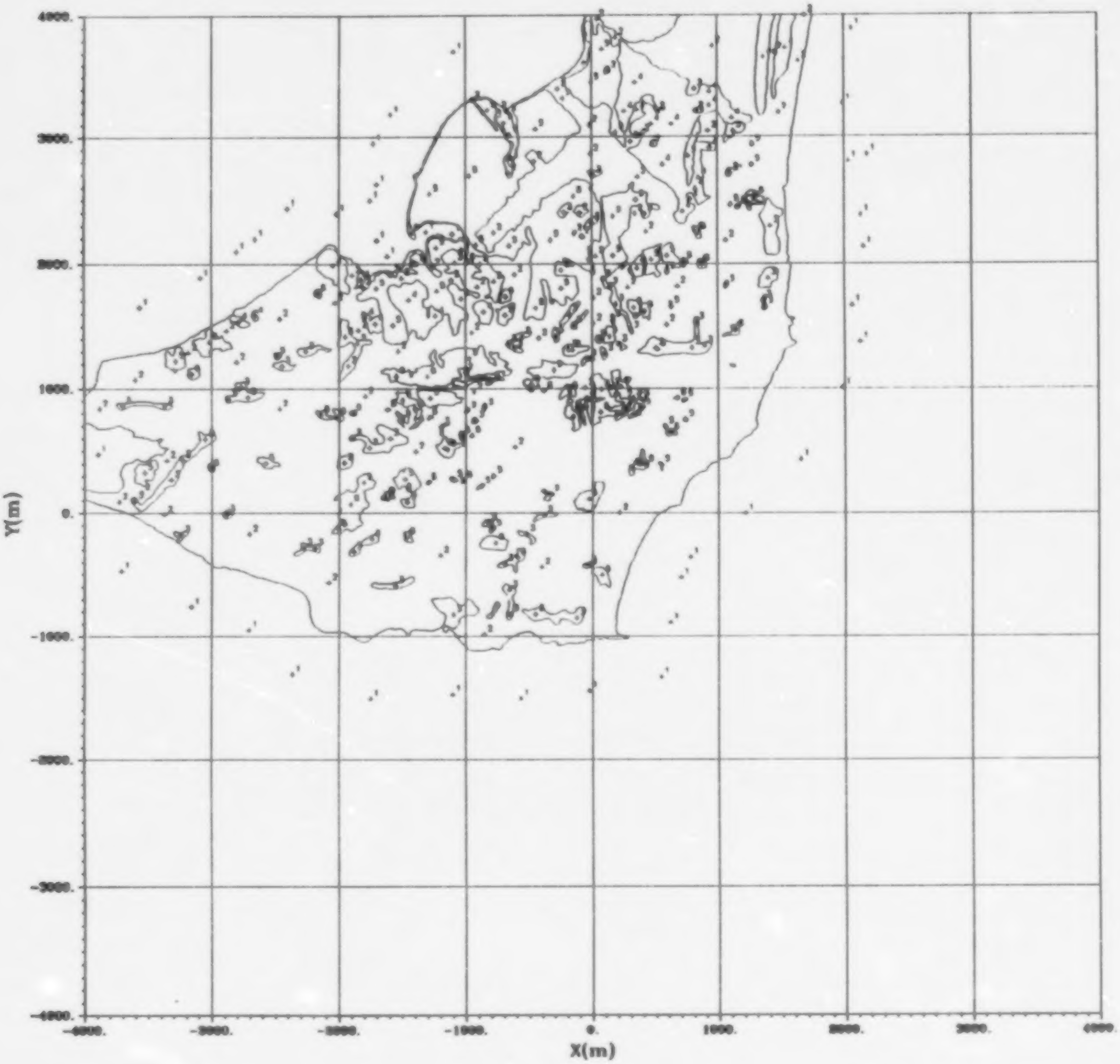

2000.
1500.
1000.
500.
0.
-500.
-1000.
-1500.
-2000.
Y(m)
-2000.
-1500.
-1000.
-500.
0.
500.
1000.
1500.
2000.
X(m)
10.
60.
70.
70.
40.
60.
70
50
60.
60.
70.
40.
30.
20
10.
40.
0.
GRIDDED TOPOGRAPHY (m)
M0 – Les Buttes Pelees 91/01/24 12:07

Figure 9 Contours of gridded topography for Les Buttes Pelées.


4000.
3000.
2000.
1000.
0.
-1000.
-2000.
-3000.
-4000.
Y(m)
-4000.
-3000.
-2000.
-1000.
0.
1000.
2000.
3000.
4000.
X(m)

ROUGHNESS BOUNDARIES AND SEEDS

M0 – Les Buttes Pelees 91/01/24 12:07

Figure 10 Digitized roughness boundaries and seeds for Les Buttes Pelées.

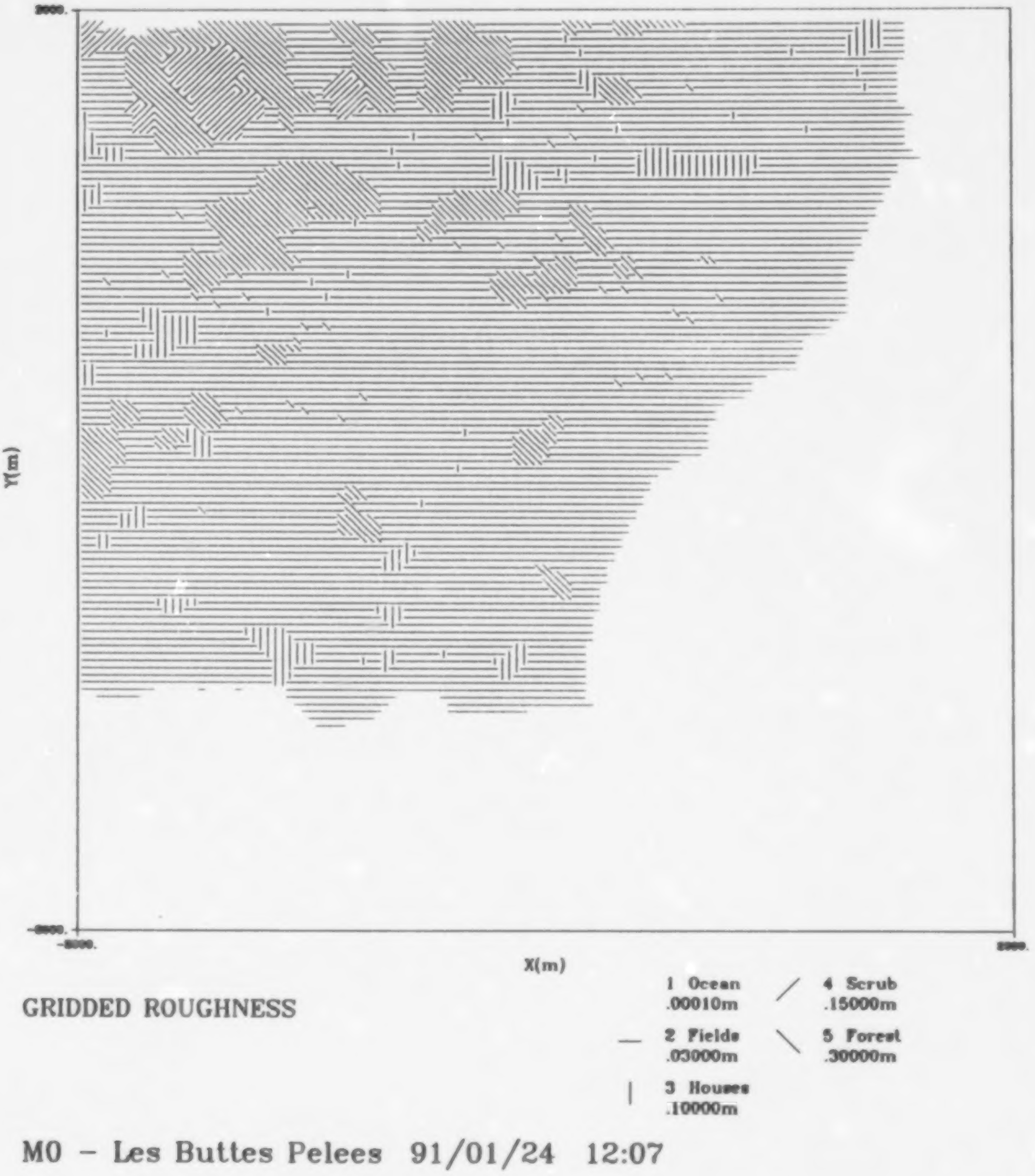

Y(m)
X(m)
GRIDDED ROUGHNESS
1 Ocean .00010m
2 Fields .03000m
3 Houses .10000m
4 Scrub .15000m
5 Forest .30000m
M0 - Les Buttes Pelees 91/01/24 12:07

Figure 11 Representation of gridded roughness for Les Buttes Pelées.

Table 8 MS-Micro/2 model parameters; Les Buttes Pelées, Bonus 300kW.

```
Project: MO - Les Buttes Pelees  91/01/23  14:33
     ------
    256          No. of X grid lines
    256          No. of Y grid lines
  -4000.         Left boundery of domain (m)
   4000.         Right boundery of domain (m)
  -4000.         Lower boundery of domain (m)
   4000.         Upper boundery of domain (m)
------
     12   No. of directions
Dir.No. / Dir.(deg) / Outer level (m) / Upstream
rough. class / Frequency (%) / Weibull C /
Weibull k
 1    000    0.     1      6.2     9.9    1.96
 2    030    0.     1      5.6    11.3    1.87
 3    060    0.     1      4.4    10.1    1.82
 4    090    0.     1      5.4     9.3    1.86
 5    120    0.     1      6.0     9.4    1.72
 6    150    0.     1      4.7     8.3    1.97
 7    180    0.     1     10.1    10.1    2.64
 8    210    0.     1     11.5     9.8    2.55
 9    240    0.     1     11.1     9.7    2.07
10    270    0.     1     13.0    11.6    2.22
11    300    0.     1     11.3    11.0    2.12
12    330    0.     1     10.7    10.7    2.05
------
MOLBP3.TCN       Topography contour file
MOLBP3.RBS       Roughness boundary file
------
      5   No. of roughness classes
Class.No. / Roughness (m) / Description
   1  1.00E-04       Ocean
   2  3.00E-02       Fields
   3  1.00E-01       Houses
   4  1.50E-01       Scrub
   5  3.00E-01       Forest
------
     0.          Origin x-shift (m)
     0.          Origin y-shift (m)
  2000.          Inner matching distance (m)
  3000.          Outer matching distance (m)
------
      1   No. of delta-z levels
Level No. / Level (m)
   1     35.00
```

the altitude above the local terrain.

4.4 WIND RESOURCE

Prediction of the effect of local terrain on the average annual wind speed begins with the annual wind direction frequencies and Weibull parameters for at least one point in the domain. For this study, this point is the site of the Îles de la Madeleine Airport anemometer.

The data for this portion of the study have been derived from the WAsP wind atlas by applying WAsP to the Airport location. A flat topography with z_o=0.0001m was assumed for the calculation of wind statistics at heights of 27, 31 and 35m. The values of frequency, Weibull C and Weibull k calculated by WAsP are listed in Tables 6 to 9.

4.5 TREATMENT OF TREES

At the Grosse Île site the terrain is characterized by a forest consisting of trees in the 6m height range. We expect these to influence not only the surface roughness but the height at which the wind speed profile drops to zero - the displacement height. Oke (1978) states that, for trees, the displacement height is equal to 2/3 of the mean height of the trees. Therefore we have chosen 4m as the displacement height and have referenced our wind resources to this level. In practical terms, this means calculating the wind resource at a height 4m below the hub height, *i.e.*, at 31m for the Bonus 450kW and at 27m for the Nordtank 300kW.

4.6 RESULTS

After the standard MS-Micro/2 programs were run to produce the normalized velocity fields for each of the twelve wind directions, a new program was used to estimate the annual energy output of a single turbine at each grid point in the central portion of the domain. For input, this program required the normalized velocity fields at hub height (or hub height minus displacement height for Grosse Île), the unperturbed wind resource (frequency, Weibull coefficients for all directions) at calculation height (obtained from WAsP analysis) and the turbine power curve. The results of this calculation for a Bonus 450kW at the Grosse Île site is shown two ways in Figures 12 and 13. Figure 12 is a contour plot of the estimated annual energy generation of a single Bonus 450kW turbine at any location. Figure 13 shows the same quantity in relief. Note that these data have taken the treed nature of the domain into account.

Once the data shown in Figure 12 were available (in the form of a grid covering the central quarter of the total domain) another new MS-Micro/2 program was invoked. Its purpose was to find the 11 points in the domain with the highest energy generation potential, with the restriction that turbines placed at those locations could not be closer than 4 rotor diameters to each other. Figure 14 shows the results of running this optimization program. The small numbered circles depict the turbine and show the rotor diameter to scale. The numbers correspond to the rank, in energy production, of the sites while the larger circles have a diameter of 4 times the rotor diameter. Note that the calculation described here did <u>not</u> take interference between individual turbines into account.

In descending order, Table 10 lists the locations, annual energy production and cumulative energy production of the turbines at the optimized locations. These data are graphed in Figure 15.

The same results for Grosse Île and the Nordtank 300kW turbine are shown in Figures 16 to 19. In the case of Les Buttes Pelées the results for the Bonus 450kW turbine are shown in Figures 20 to 23 while those for the Nordtank 300kW are shown in Figures 24 to 27.

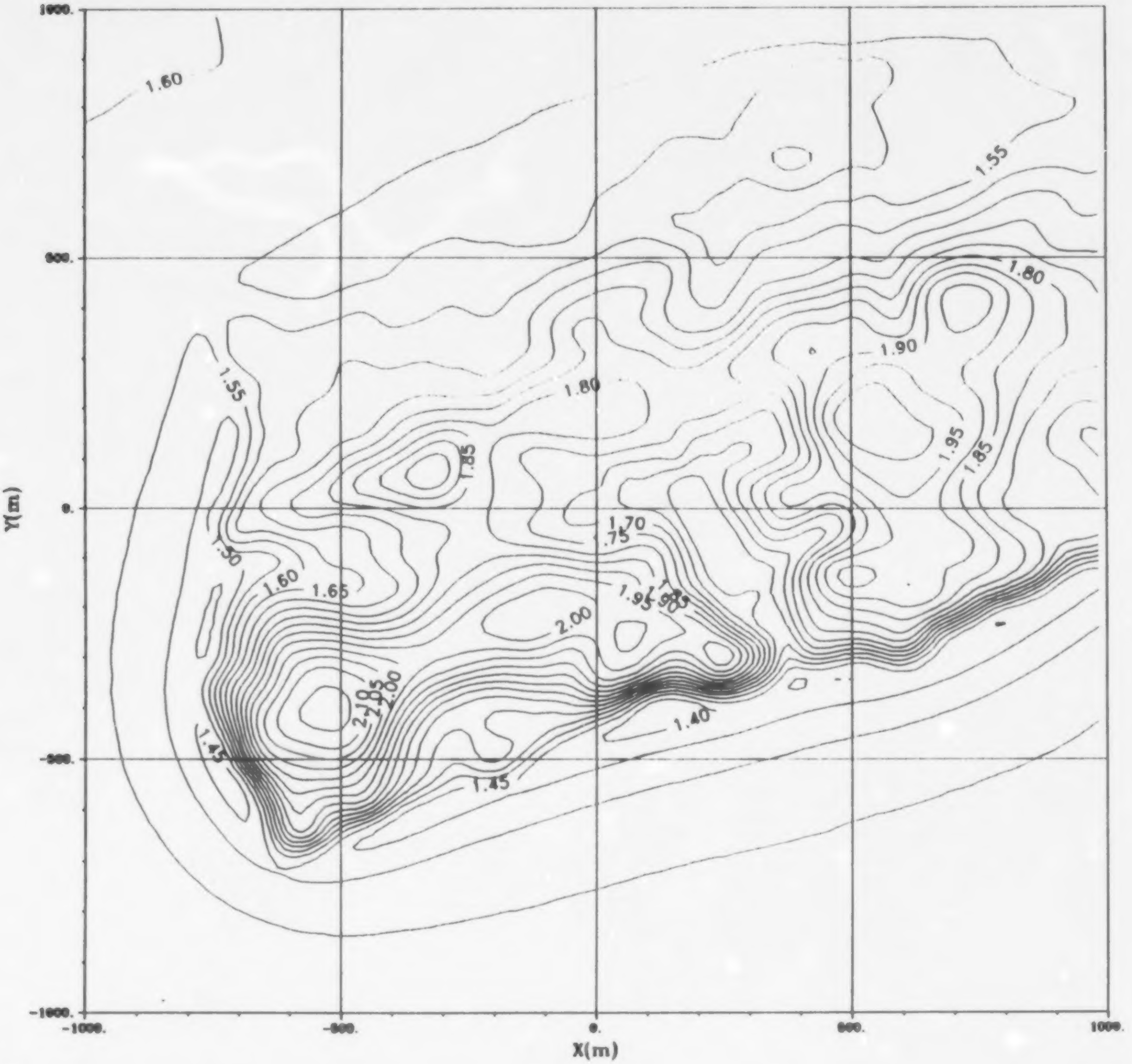
Table 9 MS-Micro/2 parameter summary; Les Buttes Pelées, Nordtank 300kW.

```
Project: NO - Les Buttes Pelees  91/01/24  12:07
     ------
    256          No. of X grid lines
    256          No. of Y grid lines
  -4000.         Left boundary of domain (m)
   4000.         Right boundary of domain (m)
  -4000.         Lower boundary of domain (m)
   4000.         Upper boundary of domain (m)
------
      12   No. of directions
Dir.No. / Dir.(deg) / Outer level (m) / Upstream
rough. class / Frequency (%) / Weibull C /
Weibull k
 1   000    0.     1     6.2     9.7    1.92
 2   030    0.     1     5.6    11.1    1.84
 3   060    0.     1     4.4     9.9    1.79
 4   090    0.     1     5.4     9.1    1.82
 5   120    0.     1     6.0     9.2    1.69
 6   150    0.     1     4.7     8.1    1.92
 7   180    0.     1    10.1     9.9    2.58
 8   210    0.     1    11.5     9.5    2.50
 9   240    0.     1    11.1     9.5    2.03
10   270    0.     1    13.0    11.4    2.18
11   300    0.     1    11.3    10.8    2.08
12   330    0.     1    10.7    10.5    2.01
------
NOLBP3.TCN       Topography contour file
NOLBP3.RBS       Roughness boundary file
------
      5   No. of roughness classes
Class.No. / Roughness (m) / Description
   1  1.00E-04       Ocean
   2  3.00E-02       Fields
   3  1.00E-01       Houses
   4  1.50E-01       Scrub
   5  3.00E-01       Forest
------
     0.          Origin x-shift (m)
     0.          Origin y-shift (m)
   2000.         Inner matching distance (m)
   3000.         Outer matching distance (m)
------
      1   No. of delta-z levels
Level No. / Level (m)
   1     31.00
```

4.7 DISCUSSION

Referring to Figure 12 as an example, it is not surprising to note that the locations with the highest energy production potential are coincident with the hills and ridges in the domain.

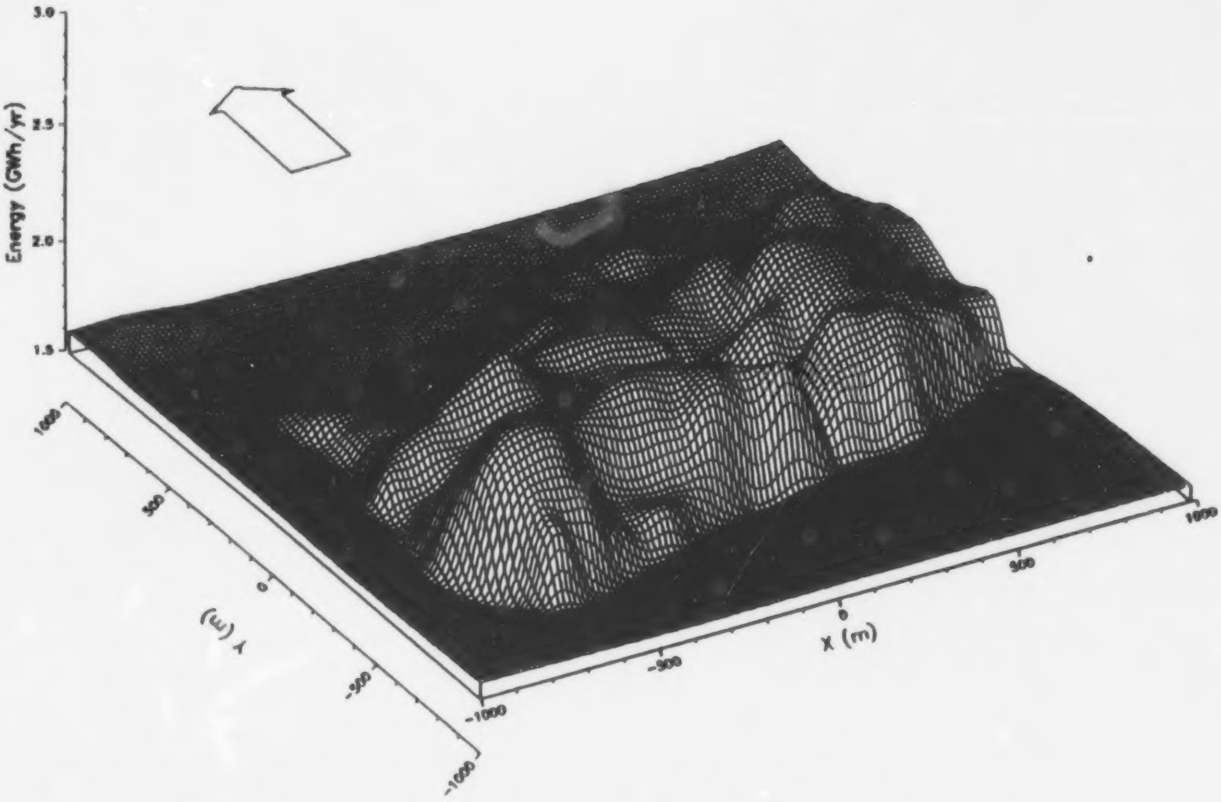
In Figure 14 it is again not surprising to find that the optimization procedure has essentially placed the turbines on the hills and ridges in the region. This has resulted



ANNUAL TURBINE ENERGY (GWh/yr)
Corrected Bonus 450 with HH->31m
Hub-height 31.0m Rotor diameter 35.0m

M0 - Grosse Ile 91/01/20 12:46

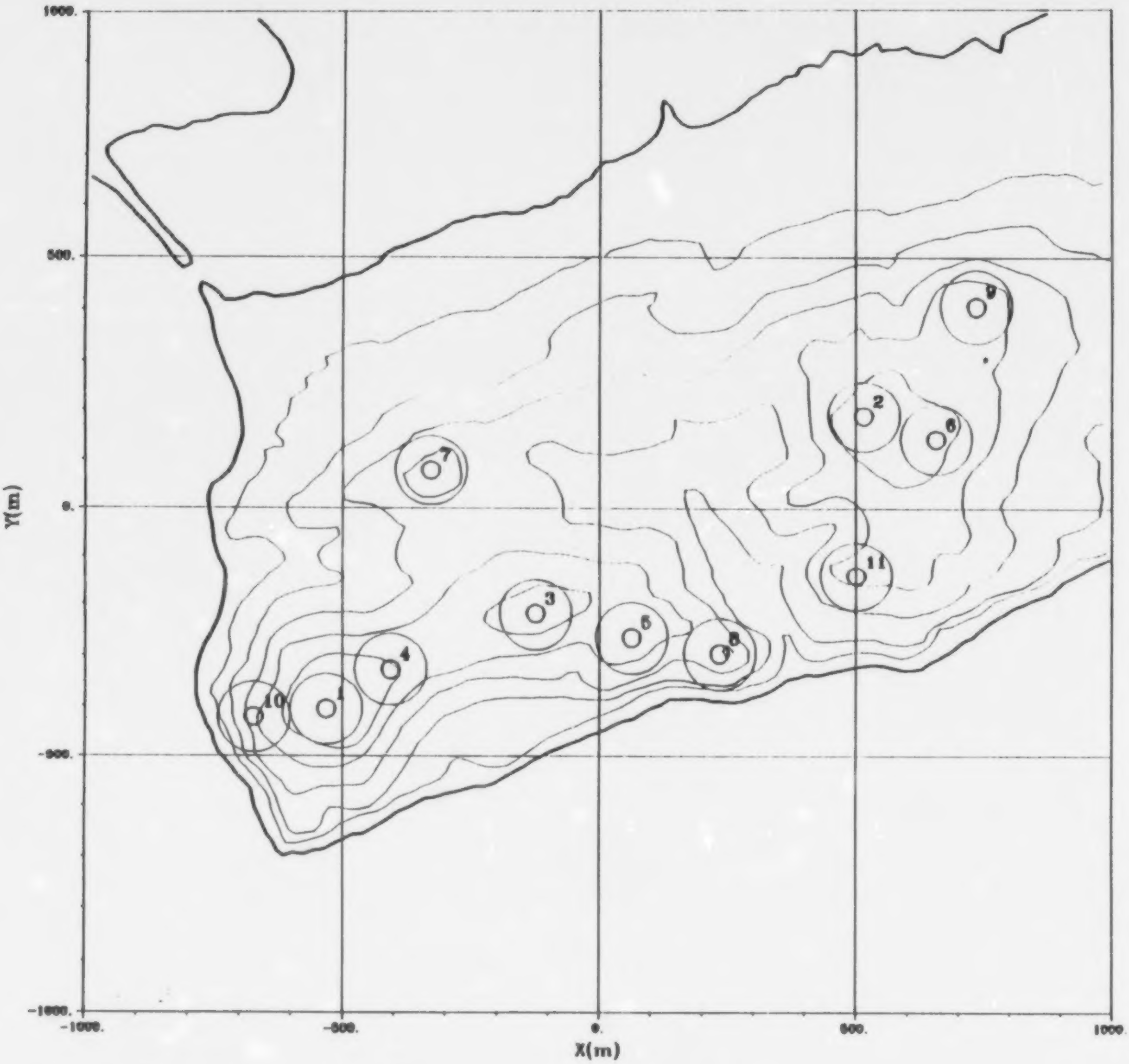
Figure 12 Contours of annual energy production.



ANNUAL TURBINE ENERGY (GWh/yr)
Corrected Bonus 450 with HH->31m
Hub-height 31.0m Rotor diameter 35.0m

M0 - Grosse Ile 91/01/20 12:46

Figure 13 Relief plot of annual energy production.


1000.
500.
0.
-500.
-1000.
Y(m)
-1000.
-500.
0.
500.
1000.
X(m)
1
2
3
4
5
6
7
8
9
10
11

OPTIMIZED TURBINE LOCATIONS

Corrected Bonus 450 with HH->31m

Hub-height: 31.0m   Rotor diameter: 35.0m

Minimum turbine separation: 4.0x rotor diameter

M0 - Grosse Ile 91/01/20 12:46

Figure 14 Map of optimized turbine locations.

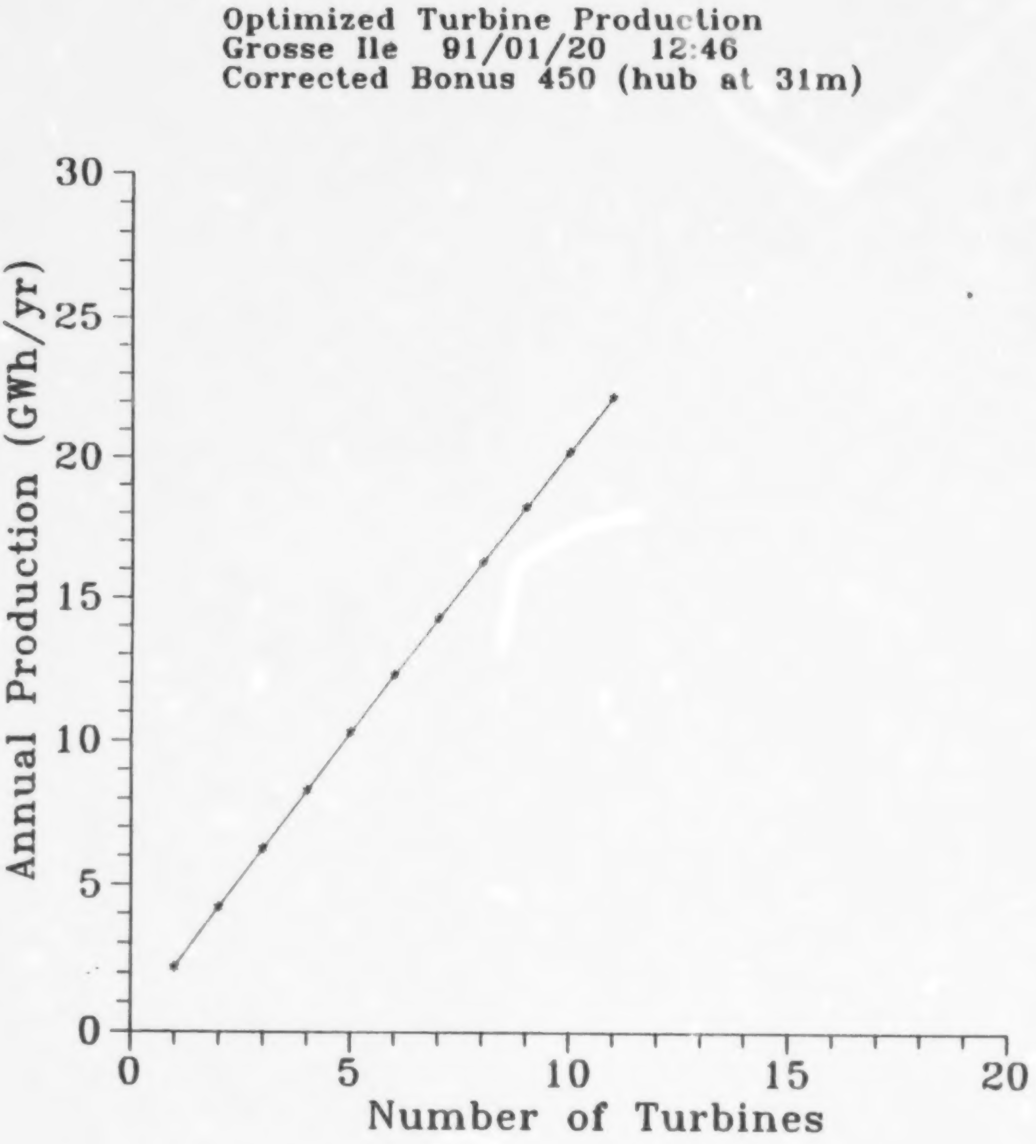
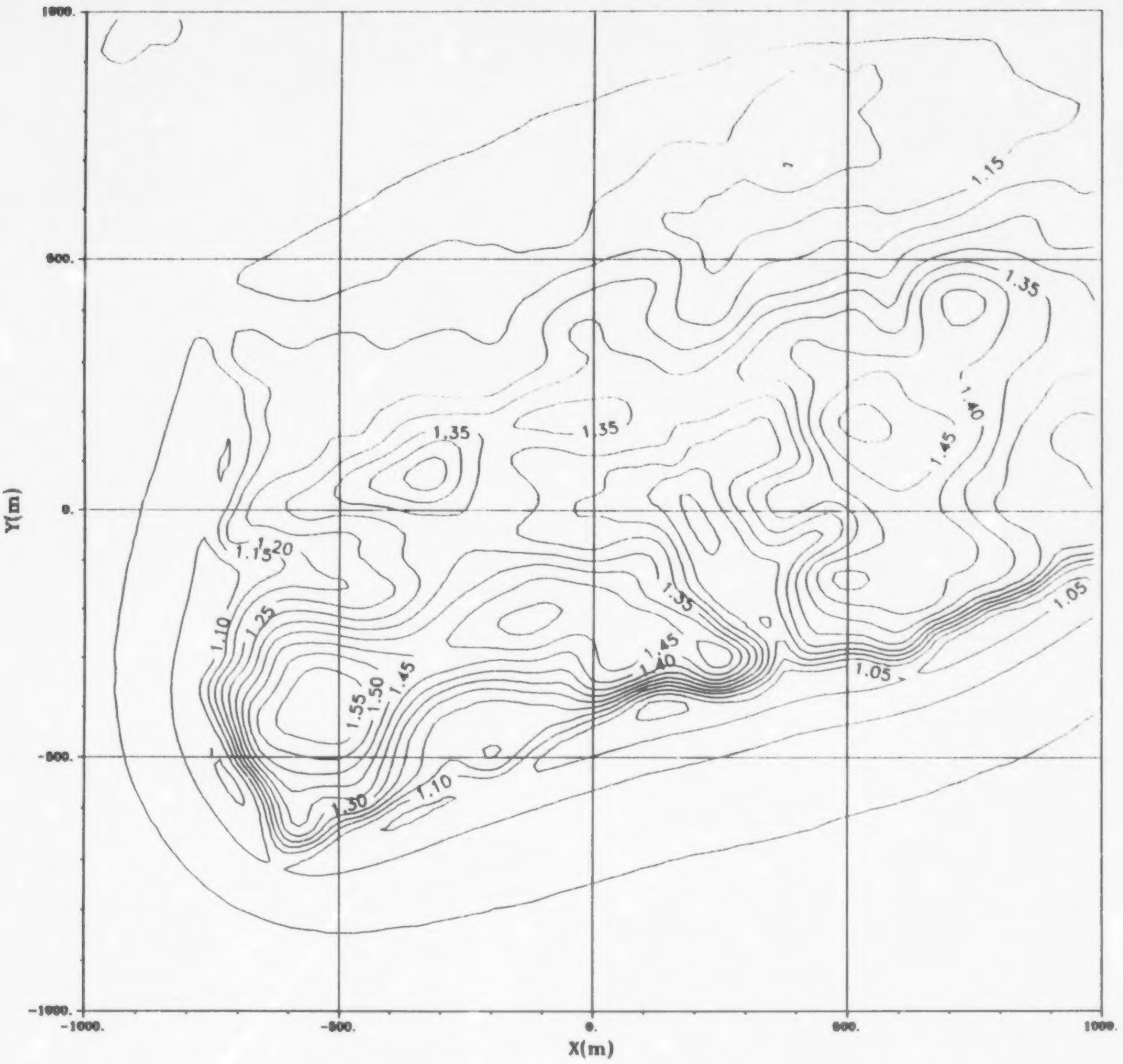


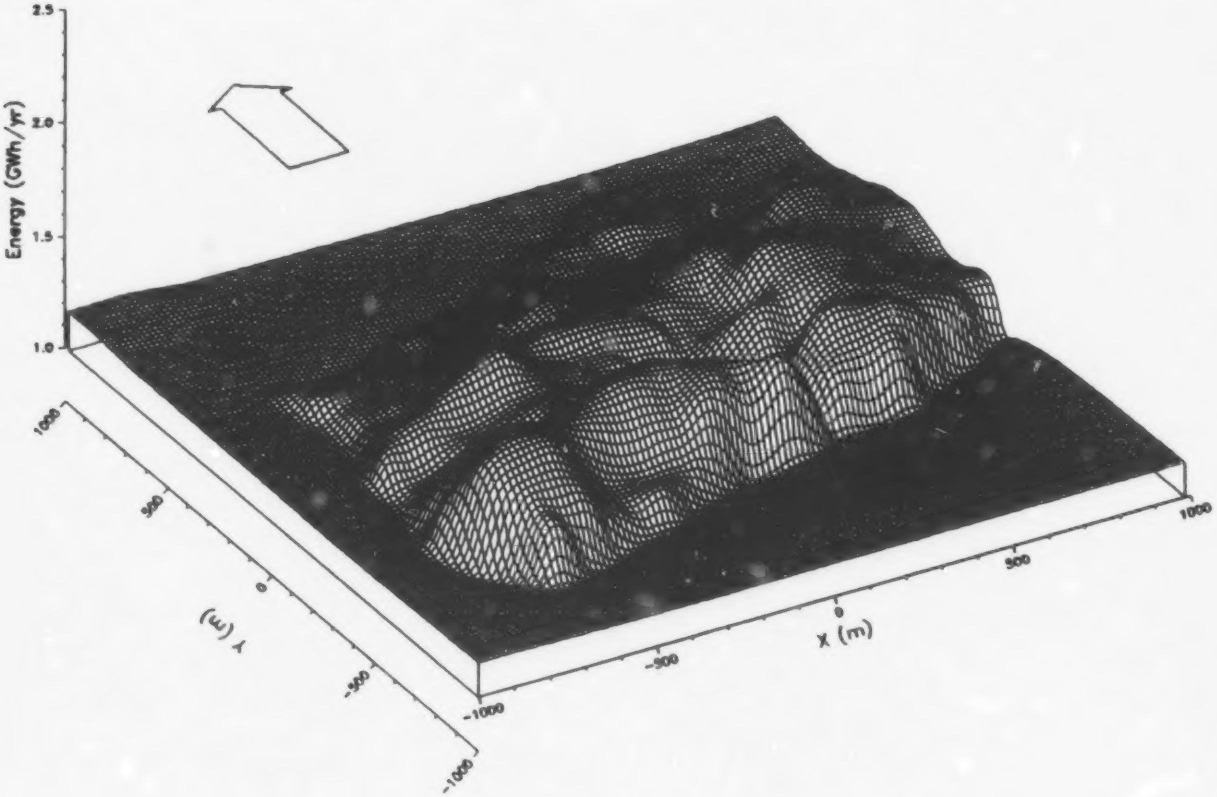
Figure 15 Annual energy production *vs.* number of turbines.



ANNUAL TURBINE ENERGY (GWh/yr)
Nordtank 300 with hub-height set to 27m
Hub-height 27.0m Rotor diameter 31.0m

M0 - Grosse Ile 91/01/18 14:58

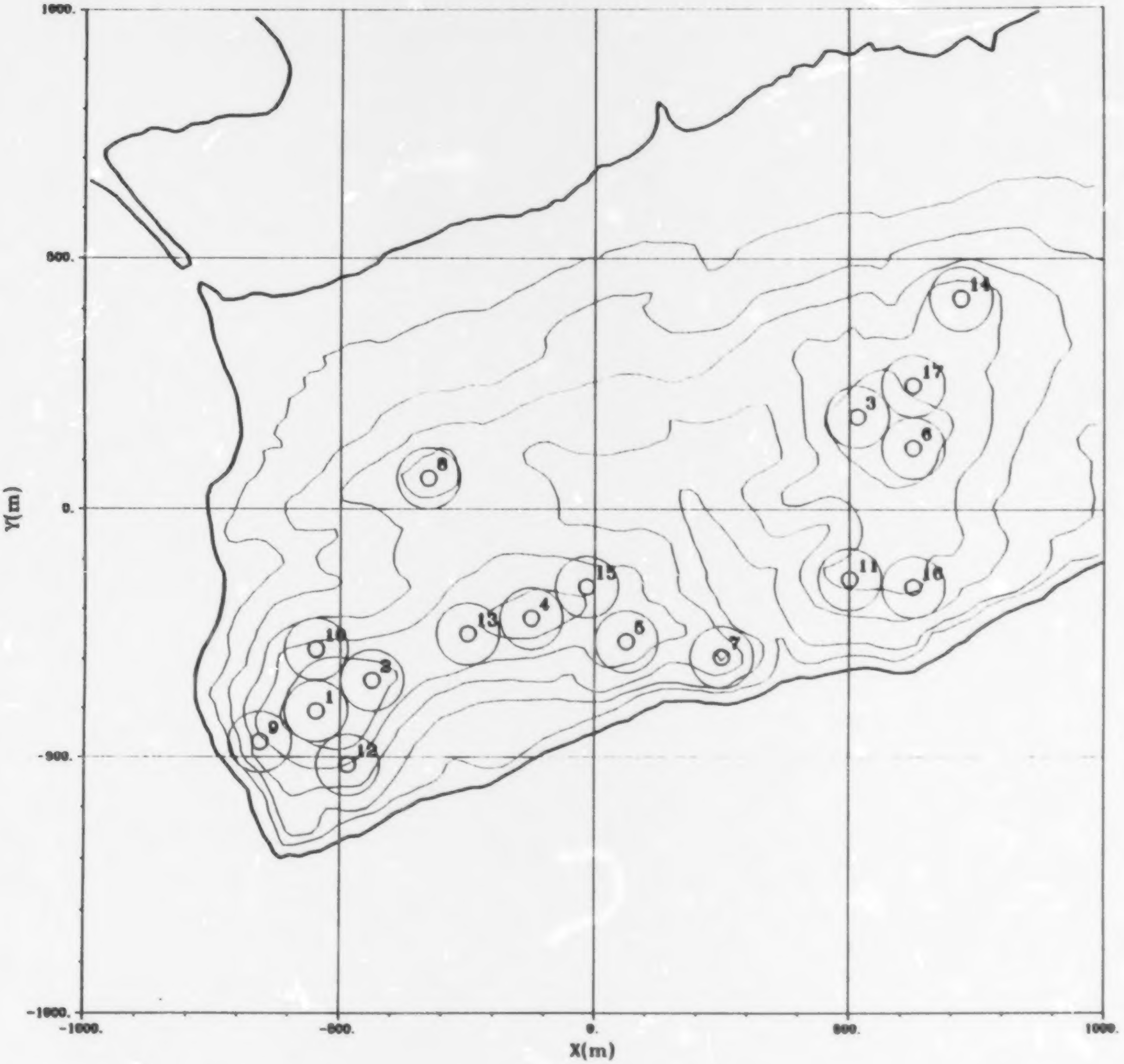
Figure 16 Contours of annual energy production.



ANNUAL TURBINE ENERGY (GWh/yr)
Nordtank 300 with hub-height set to 27m
Hub-height 27.0m   Rotor diameter 31.0m

M0 – Grosse Ile 91/01/18 14:58

Figure 17 Relief plot of annual energy production.


1000.
500.
0.
-500.
-1000.
Y(m)
-1000.
-500.
0.
500.
1000.
X(m)
14
17
3
6
8
15
11
16
13
4
5
7
10
2
1
9
12

OPTIMIZED TURBINE LOCATIONS

Nordtank 300 with hub-height set to 27m

Hub-height: 27.0m Rotor diameter: 31.0m

Minimum turbine separation: 4.0x rotor diameter

M0 - Grosse Ile 91/01/18 14:58

Figure 18 Map of optimized turbine locations.

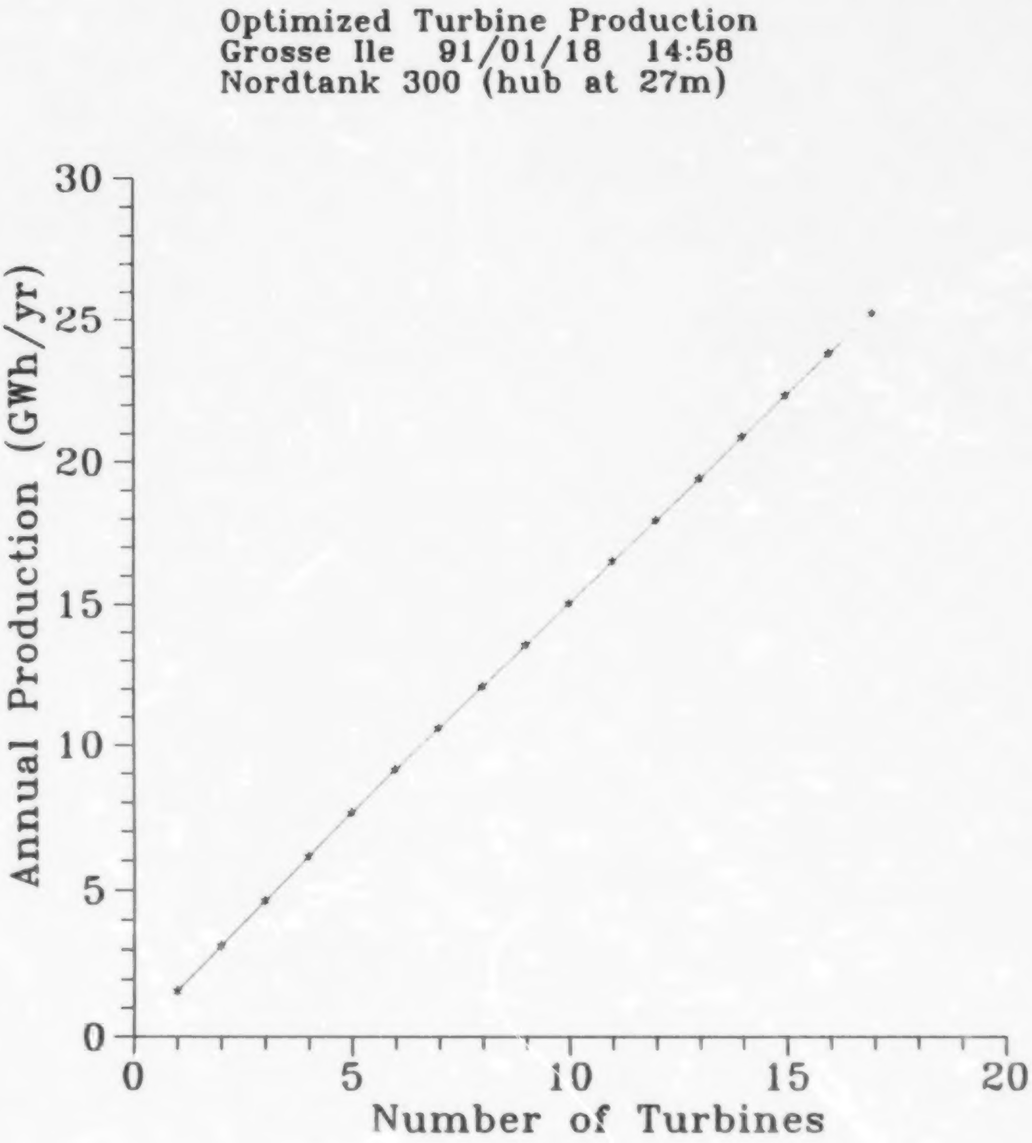
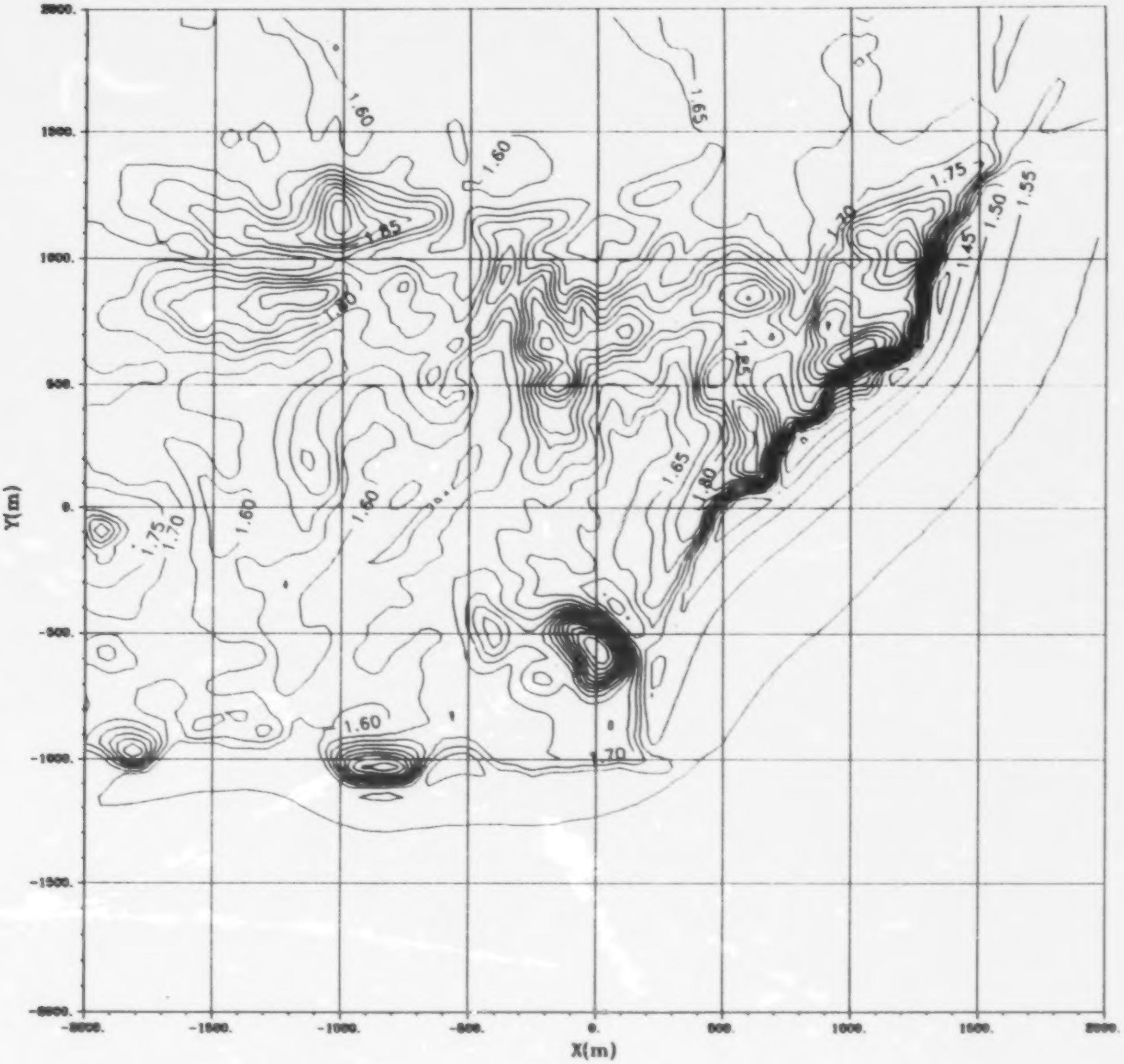


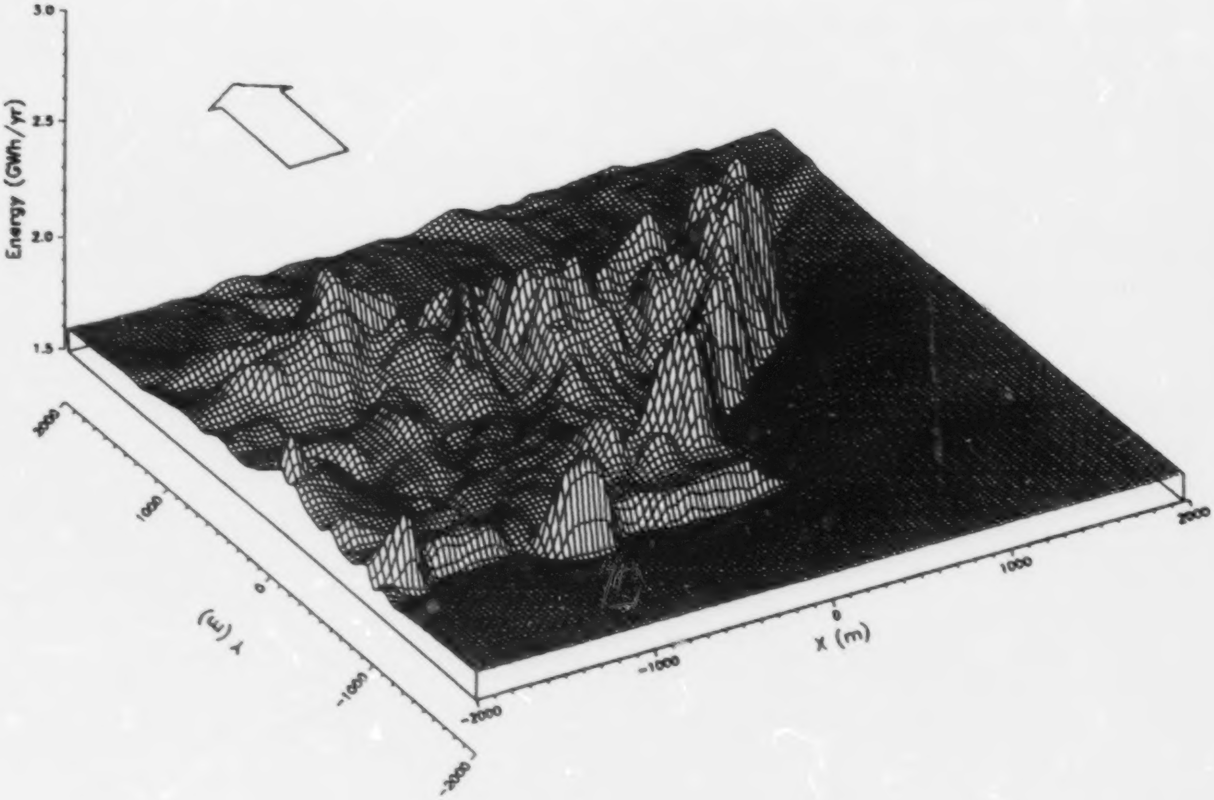
Figure 19 Annual energy production *vs.* number of turbines.


2000.
1500.
1000.
500.
0.
-500.
-1000.
-1500.
-2000.
Y(m)
-2000.
-1500.
-1000.
-500.
0.
500.
1000.
1500.
2000.
X(m)
1.60
1.65
1.60
1.75
1.70
1.50
1.55
1.45
1.85
1.80
1.85
1.65
1.80
1.60
1.60
1.75
1.70
1.60
1.70

ANNUAL TURBINE ENERGY (GWh/yr)
Corrected Bonus 450
Hub-height 35.0m Rotor diameter 35.0m

M0 - Les Buttes Pelees 91/01/23 14:33

Figure 20 Contours of annual energy production.



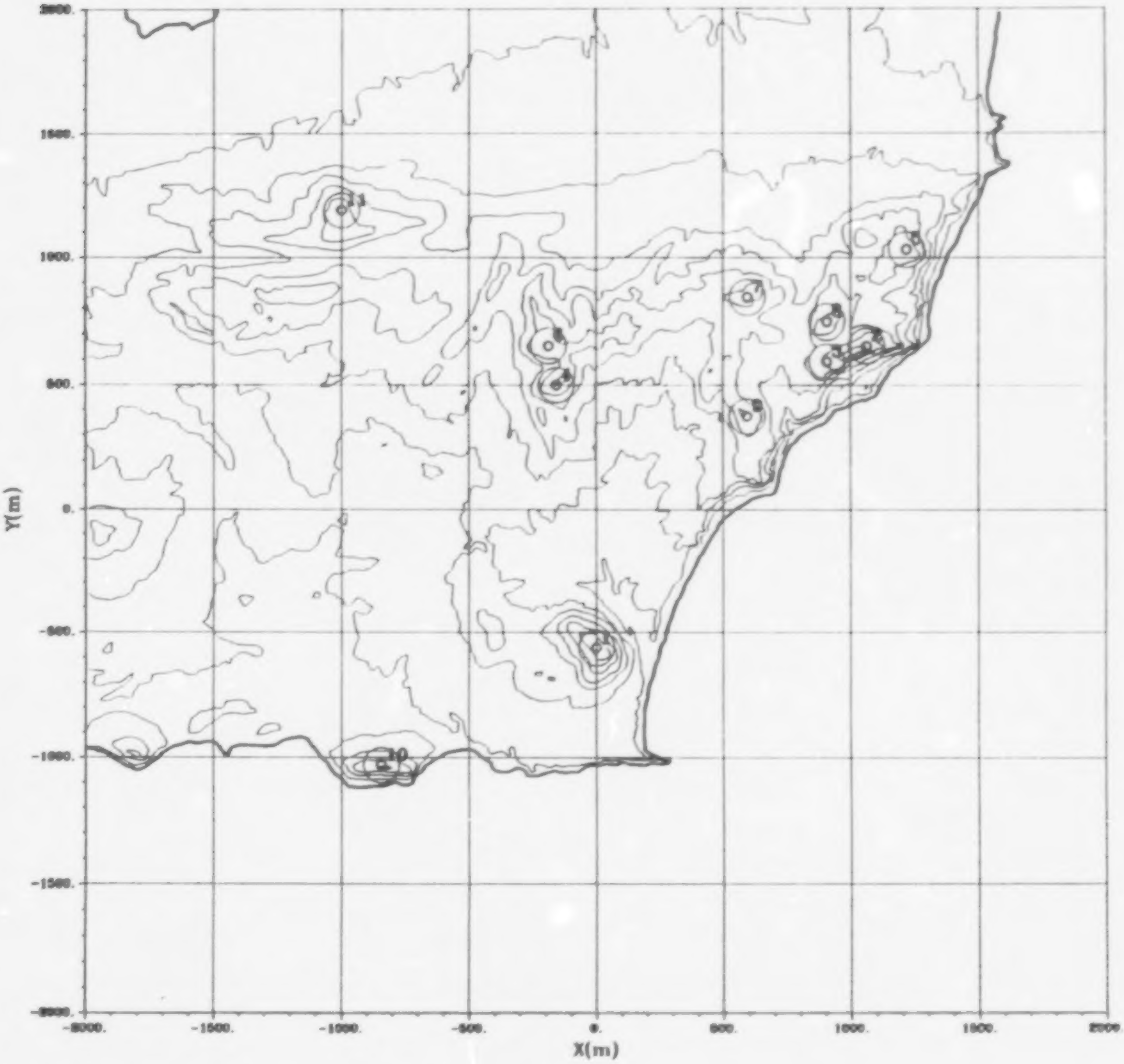
ANNUAL TURBINE ENERGY (GWh/yr)

Corrected Bonus 450

Hub-height 35.0m Rotor diameter 35.0m

M0 - Les Buttes Pelees 91/01/23 14:33

Figure 21 Relief plot of annual energy production.


2000.
1500.
1000.
500.
0.
-500.
-1000.
-1500.
-2000.
Y(m)
-2000.
-1500.
-1000.
-500.
0.
500.
1000.
1500.
2000.
X(m)
11
10

OPTIMIZED TURBINE LOCATIONS

Corrected Bonus 450

Hub–height: 35.0m Rotor diameter: 35.0m

Minimum turbine separation: 4.0x rotor diameter

M0 – Les Buttes Pelees 91/01/23 14:33

Figure 22 Map of optimized turbine locations.

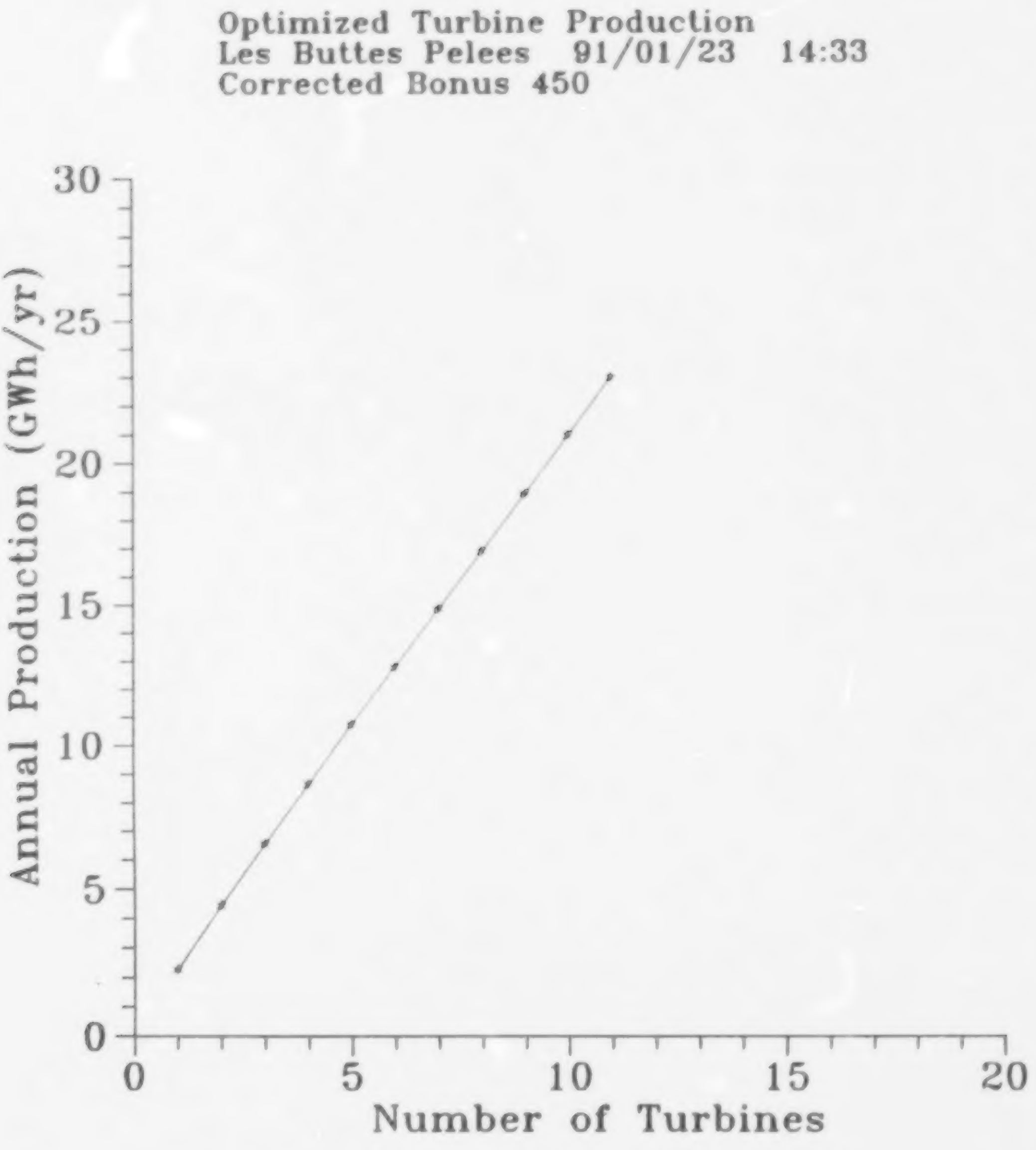
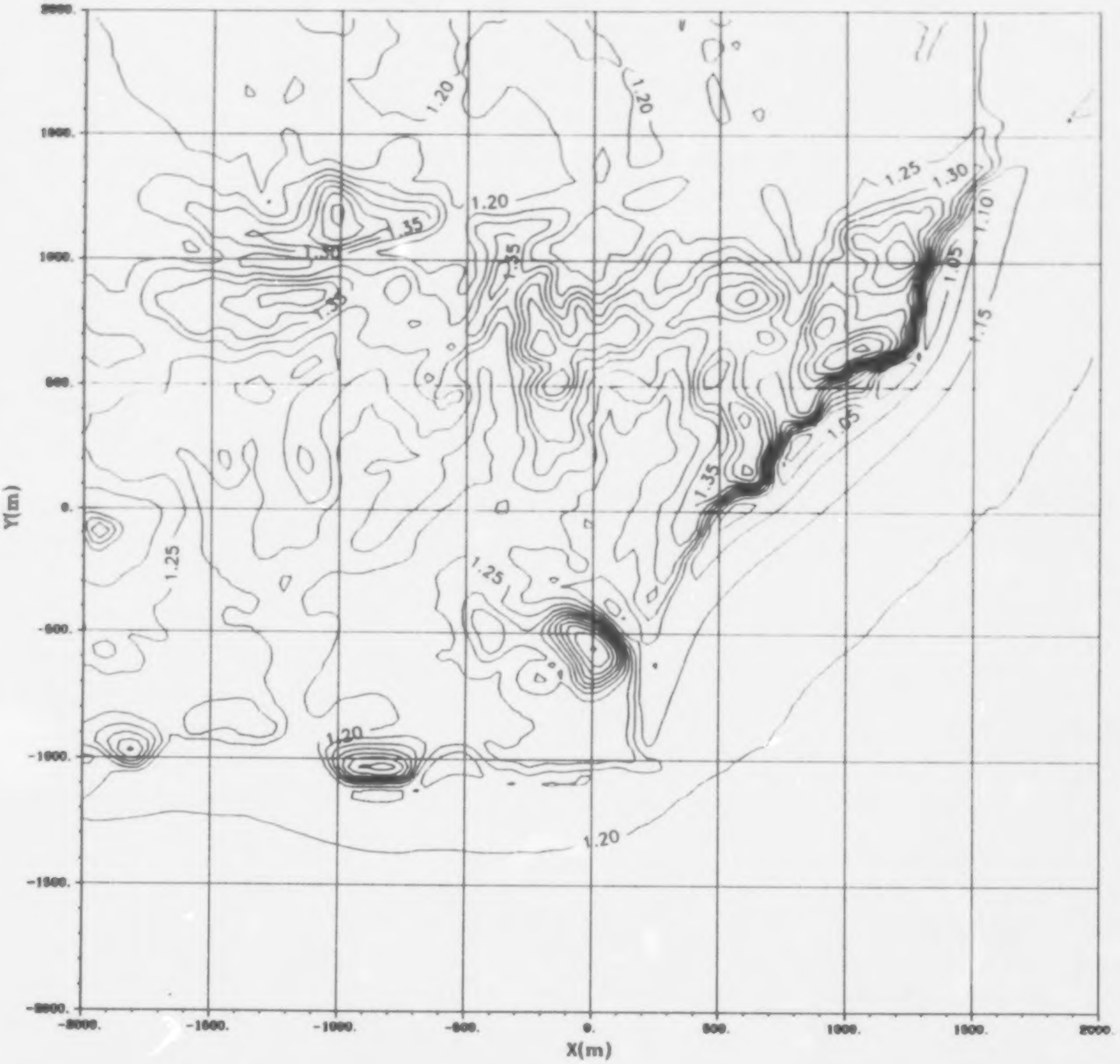


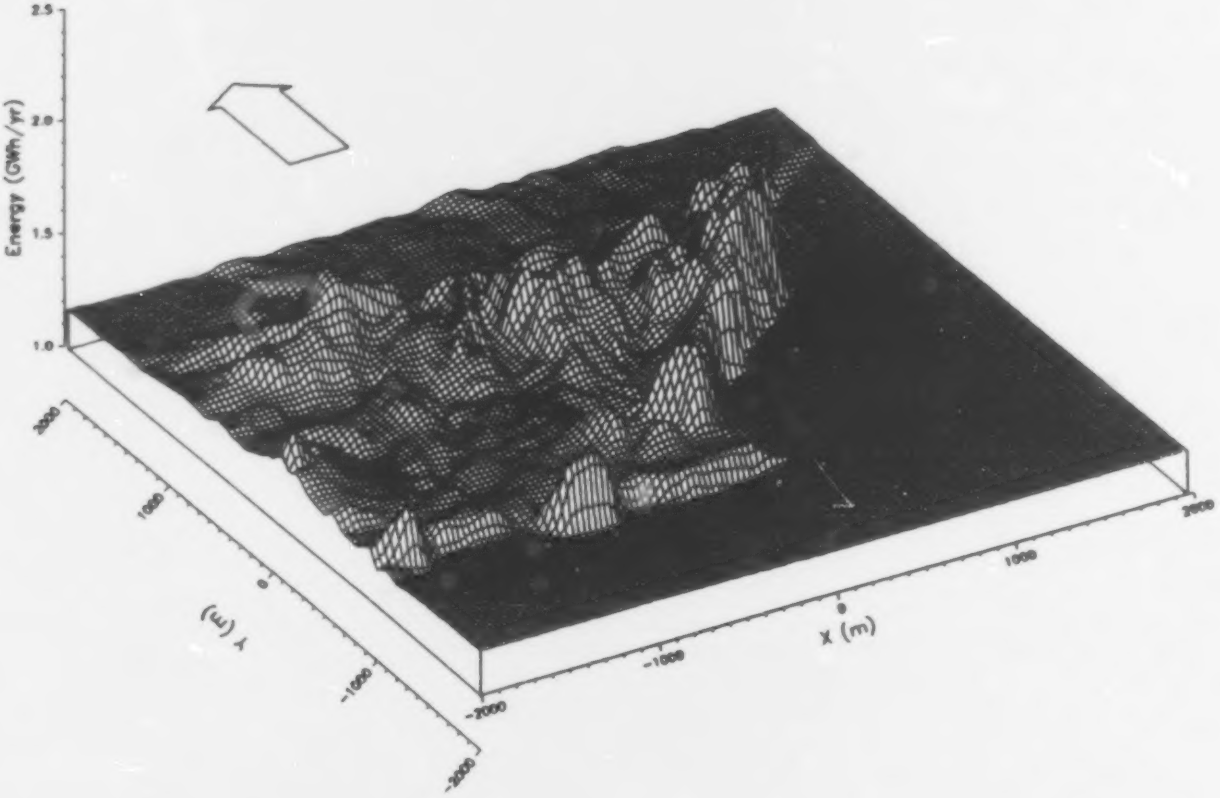
Figure 23 Annual energy production *vs.* number of turbines.



ANNUAL TURBINE ENERGY (GWh/yr)
Nordtank 300
Hub-height 31.0m Rotor diameter 31.0m

M0 – Les Buttes Pelees 91/01/24 12:07

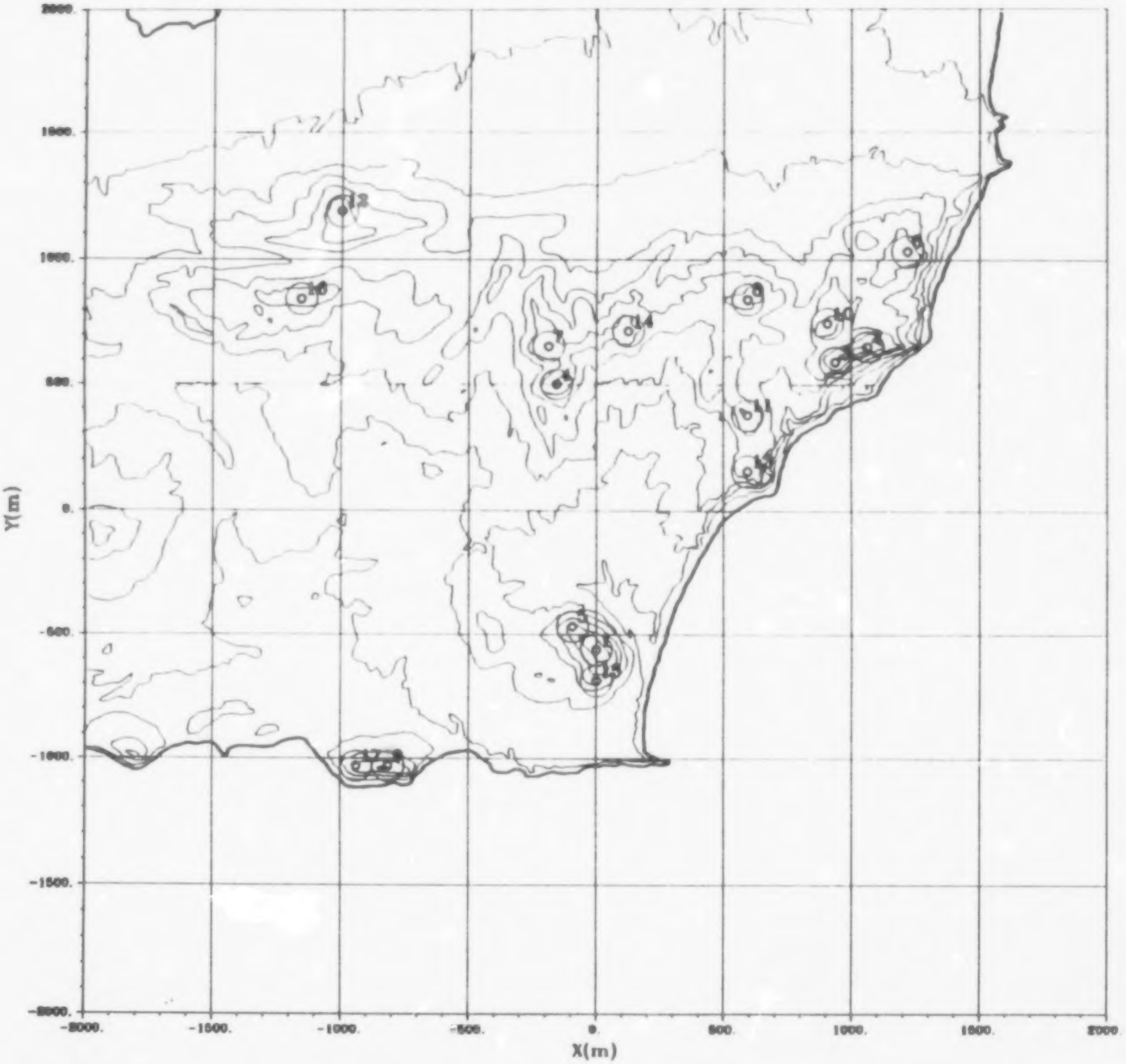
Figure 24 Contours of annual energy production.



ANNUAL TURBINE ENERGY (GWh/yr)
Nordtank 300
Hub-height 31.0m Rotor diameter 31.0m

M0 - Les Buttes Pelees 91/01/24 12:07

Figure 25 Relief plot of annual energy production.


2000.
1500.
1000.
500.
0.
-500.
-1000.
-1500.
-2000.
Y(m)
-2000.
-1500.
-1000.
-500.
0.
500.
1000.
1500.
2000.
X(m)
12
16
7
14
9
10
11
15

OPTIMIZED TURBINE LOCATIONS
Nordtank 300
Hub-height: 31.0m Rotor diameter: 31.0m
Minimum turbine separation: 4.0x rotor diameter

M0 – Les Buttes Pelees 91/01/24 12:07

Figure 26 Map of optimized turbine locations.

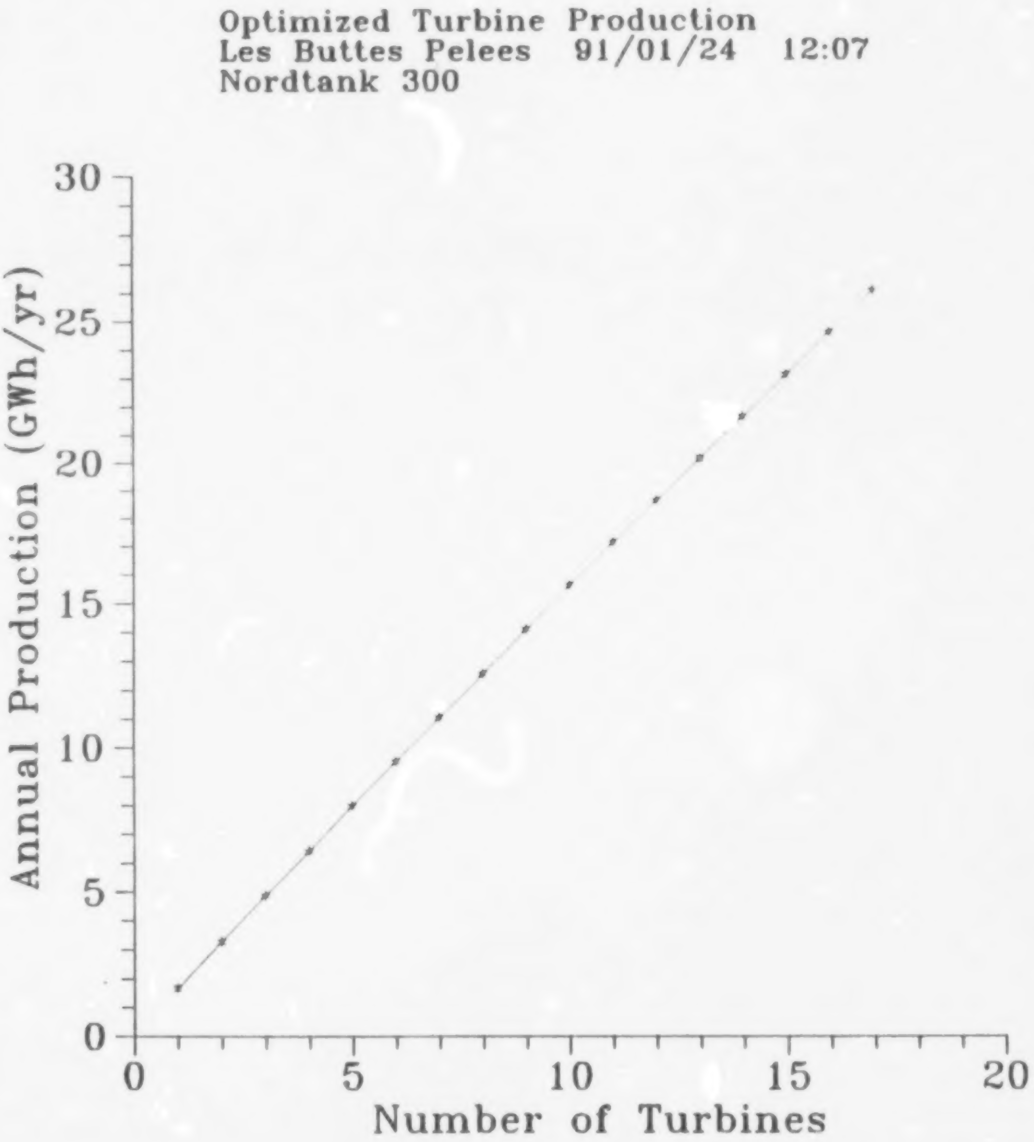


Figure 27 Annual energy production *vs.* number of turbines.

in a reasonably well dispersed optimal configuration. This can be advantageous in minimizing production loss due to turbine wake interactions but on the other hand may result in greater installation costs. One note of caution is that on steep hills, separation of the flow may occur on the lee side of the hill. This would likely be accompanied by a dramatic reduction in production and possibly an increase in turbulence intensity. It should be repeated here that the model does not predict flow separation. Therefore, it is important to be wary of placing turbines on the sides of steep hills opposite the predominant wind direction. In this instance, southeast slopes should be examined carefully.

It should also be repeated here that the annual productions listed in Table 10 have not taken energy reductions due to turbine wake interactions into account. This is justifiable in the light of the results of the WAsP and PARK analyses of Section 3. In those analyses, the efficiencies tended to be in the high ninety percent range for turbine arrays that were more crowded than the typical distribution found in this optimization. Furthermore, there is no MS-Micro/2 software available to do the interaction calculation directly, although it would in principle be possible to use the MS-Micro/2 output to generate wind resource statistics at the optimized locations and then use these data in program PARK to calculate the production reductions due to turbine interference. The next obvious step would be to perturb the optimized locations slightly and recalculate the total energy output using PARK to see whether an improvement could be made in the output. Unfortunately, program PARK is cumbersome to use and does not lend itself to this sort of iterative process. Finally, this type of procedure would entail a fairly large amount of effort in an attempt to determine the last 2 or 3% in a wind resource that can fluctuate by 10 to 15% from year to year.

One perhaps surprising result, referring to Figure 15 for example, is the linearity of the production *vs.* number-of-turbines curve. This suggests that an incremental increase in installed power does not bring a production penalty with it for the numbers we are considering here, or alternatively, that there are a large number of good sites still available.

5 SUGGESTIONS FOR FUTURE ANALYSIS

This preliminary study has provided an overall picture of the comparative wind production potential for a number of sites and a number of wind turbines on the Îles de la Madeleine. There are a number of areas which can be further investigated and/or refined.

(1) A more complete analysis of the wind resource at the Airport anemometer could be undertaken. In particular, the analysis of the effect of obstacles in the vicinity of the anemometer would improve the quality of the wind statistics. It might also be worthwhile to examine all of the ship data in the region of the islands for purposes of comparison. This would be relatively easy to do.

(2) The actual hub height power curve for the Bonus 450 turbine should be obtained for further analysis, although it is unlikely that it would be significantly different from the corrected curve calculated for the purposes of this study.

Table 10 Optimization study results.

(a)

```
Project Name:  MO - Grosse Ile  91/01/20  12:46
Turbine:  Corrected Bonus 450 with HH->31m
Hub-height: 31.0m    Rotor diameter: 35.0m
Minimum turbine seperation:  4.0x rotor diameter

No.          X       Y         Annual  Cumulative
           (m)     (m)     Production      Annual
                            (GWh/yr)   Production
                                         (GWh/yr)
-------------------------------------------------
  1      -531.   -406.          2.164       2.164
  2       516.    188.          2.049       4.214
  3      -125.   -219.          2.042       6.256
  4      -406.   -328.          2.030       8.286
  5        63.   -266.          2.014      10.300
  6       656.    141.          2.002      12.302
  7      -328.     78.          1.991      14.293
  8       234.   -297.          1.981      16.274
  9       734.    406.          1.976      18.250
 10      -672.   -422.          1.976      20.226
 11       500.   -141.          1.974      22.200
```

(b)

```
Project Name:  MO - Grosse Ile  91/01/18  14:58
Turbine:  Nordtank 300 with hub-height set to 27m
Hub-height: 27.0m    Rotor diameter: 31.0m
Minimum turbine seperation:  4.0x rotor diameter

No.          X       Y         Annual  Cumulative
           (m)     (m)     Production      Annual
                            (GWh/yr)   Production
                                         (GWh/yr)
-------------------------------------------------
  1      -547.   -406.          1.586       1.586
  2      -438.   -344.          1.526       3.112
  3       516.    188.          1.515       4.627
  4      -125.   -219.          1.509       6.136
  5        63.   -266.          1.494       7.630
  6       625.    125.          1.485       9.115
  7       250.   -297.          1.483      10.598
  8      -328.     63.          1.479      12.077
  9      -656.   -469.          1.478      13.555
 10      -547.   -281.          1.476      15.031
 11       500.   -141.          1.468      16.498
 12      -484.   -516.          1.466      17.964
 13      -250.   -250.          1.464      19.428
 14       719.    422.          1.462      20.891
 15       -16.   -156.          1.461      22.352
 16       625.   -156.          1.448      23.800
 17       625.    250.          1.439      25.238
```

(c)

```
Project Name: MO - Les B. Pelees  91/01/23  14:33
Turbine:  Corrected Bonus 450
Hub-height: 35.0m    Rotor diameter: 35.0m
Minimum turbine seperation:  4.0x rotor diameter

No.          X       Y         Annual  Cumulative
           (m)     (m)     Production      Annual
                            (GWh/yr)   Production
                                         (GWh/yr)
-------------------------------------------------
  1         0.   -563.          2.254       2.254
  2      1063.    656.          2.185       4.439
  3       906.    594.          2.106       6.545
  4      -156.    500.          2.096       8.641
  5      1219.   1031.          2.088      10.729
  6      -188.    656.          2.068      12.797
  7       594.    844.          2.056      14.853
  8       906.    750.          2.056      16.908
  9       594.    375.          2.051      18.959
 10      -844.  -1031.          2.039      20.998
 11     -1000.   1188.          2.037      23.035
```

(d)

```
Project Name: MO - Les B. Pelees  91/01/24  12:07
Turbine:  Nordtank 300
Hub-height: 31.0m    Rotor diameter: 31.0m
Minimum turbine seperation:  4.0x rotor diameter

No.          X       Y         Annual  Cumulative
           (m)     (m)     Production      Annual
                            (GWh/yr)   Production
                                         (GWh/yr)
-------------------------------------------------
  1         0.   -563.          1.657       1.657
  2      1063.    656.          1.613       3.270
  3       938.    594.          1.587       4.858
  4      -156.    500.          1.552       6.410
  5       -94.   -469.          1.550       7.960
  6      1219.   1031.          1.543       9.503
  7      -188.    656.          1.536      11.039
  8       594.    844.          1.528      12.566
  9      -813.  -1031.          1.527      14.094
 10       906.    750.          1.524      15.618
 11       594.    375.          1.523      17.142
 12     -1000.   1188.          1.512      18.654
 13       594.    156.          1.508      20.162
 14       125.    719.          1.498      21.659
 15         0.   -688.          1.490      23.150
 16     -1156.    844.          1.484      24.634
 17      -938.  -1031.          1.484      26.119
```

(3) If PARK is to be used for a more refined analysis of the optimized turbine configurations an attempt should be made to obtain the actual thrust coefficient curves for the turbines under consideration.

(4) The optimization procedure is based only on the maximization of wind energy production. At a further stage of the project it would be straight-forward to add other criteria to the optimization procedure. These might include exclusion

zones where turbines could not be erected for engineering or environmental reasons, the minimization of distances between turbines, *etc.*

(5) It would be interesting to repeat the optimization studies using the year-by-year wind resource data, rather than the six year average. This would give an indication of the yearly variation in total production that might be expected.

(6) It is important to emphasize that no numerical study is a substitute for *in situ* measurements of the wind resource. This should always be done before committing resources to a project of this magnitude.

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APPENDIX A

Iles de la Madeleine
Parc d'éoliennes
Liste des sites à étudier
90-11-26

Site No 1: Grosse Ile

Position géographique: 61° 32,6" Ouest, 47° 36,9" Nord

Description: Pointe Rockhill, colline Rock Mountain, situées sur Grosse Ile.

Site No 2: Les Buttes Pelées

Position géographique:
61° 45,8" Ouest, 47° 24,4" Nord
et 61° 46,6" Ouest, 47° 24,4" Nord

Description: deux massifs de collines situées sur la rive sud-est de, l'Ile du Havre aux Maisons à 1,5 km au Nord de la Butte Ronde et immédiatement au sud du village Arsenault.

Site No 3: La Dune du Nord

Position géographique: 61° 44,8" Ouest, 47° 30,0" Nord

Description: bande sablonneuse vallonnée de 250 à 300 m de largeur, située à environ 4,5 km au sud-ouest de la Pointe-au-Loup, centrée là où le Pont du Détroit rejoint la Dune du Nord et qui serait aménagée sur une longueur de 2 à 4 km.

Site No 4: La Dune du Sud - A

Position géographique: 61° 45,1" Ouest, 47° 27,7" Nord

Description: bande sablonneuse vallonnée longeant la route 199 sur son coté ouest jusqu'au Pont du Détroit. Le niveau du sol y présente des "sillons" qui sont vraisemblablement des vestiges des anciennes limites de plage et qui ont des amplitudes de 3 à 4 m.

Site No 5: La Dune du Sud - B

Position géographique: 61° 44,3" Ouest, 47° 28,0 " Nord

Description: bande sablonneuse d'environ 250 à 300 m de largeur située entre la route 199 (et le chemin de la Cormorandière) et l'eau du Golfe du Saint-Laurent, à proximité du site de l'éolienne expérimentale.

LUNCHEON ADDRESS

Wednesday, November 6

ALLOCUTION DE M. JEAN GIROUX
SOUS-MINISTRE ASSOCIÉ À L'ÉNERGIE
AU MINISTÈRE DE L'ÉNERGIE ET DES RESSOURCES

DANS LE CADRE DE LA CONFÉRENCE
"ÉNERGIE ÉOLIENNE '91"

ORGANISÉE PAR L'ASSOCIATION CANADIENNE
DE L'ÉNERGIE ÉOLIENNE

MERCREDI, 6 NOVEMBRE 1991
LE GRAND HÔTEL, MONTRÉAL

SECTEUR ÉNERGIE

1991-10-10

MESDAMES, MESSIEURS,

AU NOM DE LA MINISTRE DE L'ÉNERGIE ET DES RESSOURCES, MME LISE BACON, PRÉSENTEMENT EN MALAISIE, C'EST AVEC PLAISIR QUE J'AI ACCEPTÉ L'INVITATION LANCÉE AU MINISTÈRE DE L'ÉNERGIE ET DES RESSOURCES, DE PARTICIPER À LA CONFÉRENCE "ÉNERGIE ÉOLIENNE '91". LE GOUVERNEMENT DU QUÉBEC RECONNAÎT LE DYNAMISME DE L'ASSOCIATION CANADIENNE DE L'ÉNERGIE ÉOLIENNE ET IL A VOULU SOULIGNER SON RÔLE DE RASSEMBLEUR DES INTERVENANTS DU SECTEUR DE L'ÉNERGIE ÉOLIENNE EN ACCORDANT SON APPUI À L'ORGANISATION DE CETTE CONFÉRENCE.

LE PROGRAMME DE LA CONFÉRENCE MONTRE QU'IL EXISTE DES RESSOURCES ET DES COMPÉTENCES SIGNIFICATIVES EN ÉNERGIE ÉOLIENNE AU QUÉBEC ET AU CANADA. VOS EXPÉRIENCES ET VOS TRAVAUX MÉRITENT D'ÊTRE DIFFUSÉS TANT CHEZ LES INTERVENANTS DU MILIEU QUE DANS LE GRAND PUBLIC. CELUI-CI EST D'AILLEURS DE PLUS EN PLUS SENSIBILISÉ AUX SOURCES

D'ÉNERGIES RENOUVELABLES ET S'INTÉRESSE AU CONCEPT DU DÉVELOPPEMENT DURABLE.

FIRST, I WOULD LIKE TO OUTLINE THE QUÉBEC GOVERNMENT'S POLICY ON THE DEVELOPMENT OF RENEWABLE ENERGIES, AS PART OF A GLOBAL EFFORT TO MANAGE ITS ENERGY SUPPLIES. AFTER, THAT I WOULD LIKE TO TALK TO YOU ABOUT AN ASSISTANCE PROGRAM THAT HAS BEEN CREATED TO HELP THE DEVELOPMENT OF ENERGY TECHNOLOGIES AND WHICH CONSTITUTES THE GOVERNMENT'S MAIN TOOL FOR STIMULATING RESEARCH AND DEVELOPMENT IN THE FIELD OF RENEWABLE ENERGIES. FINALLY, I WOULD LIKE TO SHARE MY OWN THOUGHTS ON THE DEVELOPMENT OF RENEWABLE ENERGIES AND, IN PARTICULAR, ON THE ROLE OF WIND ENERGY IN QUÉBEC.

LA POLITIQUE ÉNERGÉTIQUE

QU'ENTEND-T-ON PAR "MAÎTRISER L'ÉNERGIE?" PRISE À LA LETTRE, CETTE EXPRESSION A UN SENS PLUTÔT LARGE: MAÎTRISER L'ÉNERGIE SIGNIFIE EN EFFET METTRE AU SERVICE DE LA COLLECTIVITÉ LES DIVERSES TECHNIQUES DE PRODUCTION, DE TRANSFORMATION OU D'UTILISATION DES DIFFÉRENTES RESSOURCES ÉNERGÉTIQUES.

PLUS SPÉCIFIQUEMENT, CETTE NOTION DE LA "MAÎTRISE DE L'ÉNERGIE", CORRESPOND AUX ACTIVITÉS VISANT À ACCROÎTRE L'EFFICACITÉ DANS LA CONSOMMATION D'ÉNERGIE ET LES EFFORTS TENDANT À OBTENIR DE MEILLEURS RENDEMENTS DANS LA PRODUCTION DE L'ÉNERGIE.

EN GÉNÉRAL, LES RESSOURCES SONT DIFFICILES À MOBILISER ET LES RÉSULTATS DES EFFORTS D'ACCROISSEMENT DE L'EFFICACITÉ ÉNERGÉTIQUE S'ÉVALUENT SOUVENT SUR DE LONGUES

PÉRIODES. DE PLUS, LA QUANTIFICATION MÊME DES PHÉNOMÈNES EST DIFFICILE.

CEPENDANT, LES ENJEUX DONNENT À L'ÉTAT EN CE DOMAINE UNE RESPONSABILITÉ PARTICULIÈRE ET LE GOUVERNEMENT DU QUÉBEC A EXPLICITEMENT RETENU LA MAÎTRISE DE L'ÉNERGIE COMME UN DES OBJECTIFS DE SA POLITIQUE ÉNERGÉTIQUE. ELLE REPRÉSENTE EN EFFET, À PLUSIEURS ÉGARDS, UNE POLICE D'ASSURANCE CONTRE LES ALÉAS DE LA CONJONCTURE ÉNERGÉTIQUE INTERNATIONALE. AU PLAN DE LA CONSOMMATION, UNE PLUS GRANDE EFFICACITÉ DANS L'UTILISATION DE L'ÉNERGIE A UN EFFET BÉNÉFIQUE POUR LA PROTECTION DE L'ENVIRONNEMENT. L'ÉNERGIE ÉCONOMISÉE CORRESPOND DIRECTEMENT À UNE RÉDUCTION DES IMPACTS ENVIRONNEMENTAUX D'ORIGINE ÉNERGÉTIQUE ET À UNE RÉDUCTION DE LA DÉPENDANCE PAR RAPPORT AUX ÉNERGIES IMPORTÉES. DE MÊME, AU PLAN DE LA PRODUCTION, LE DÉVELOPPEMENT DE CERTAINES FILIÈRES D'ÉNERGIE NON CONVENTIONNELLE PEUT

APPORTER DES ÉLÉMENTS DE SOLUTION À DES PROBLÈMES DE POLLUTION ET PEUT ACCROÎTRE L'AUTONOMIE ÉNERGÉTIQUE.

ENFIN, ET SURTOUT, LA MAÎTRISE DE L'ÉNERGIE EST SOURCE D'UNE PRODUCTIVITÉ ET D'UNE CAPACITÉ CONCURRENTIELLE ACCRUE POUR NOS ENTREPRISES.

AU COURS DES DERNIÈRES ANNÉES, DES PROGRÈS CONSIDÉRABLES ONT ÉTÉ ACCOMPLIS EN MATIÈRE D'EFFICACITÉ ÉNERGÉTIQUE. DE 1971 À 1986, LE SECTEUR RÉSIDENTIEL A CONNU UNE BAISSE MOYENNE DE CONSOMMATION D'ÉNERGIE PAR MÉNAGE DE PLUS DU TIERS, NOTAMMENT GRÂCE À DE MEILLEURES MESURES D'ISOLATION ET À L'AMÉLIORATION DES ÉQUIPEMENTS. MÊME S'IL RESTE DIFFICILE DE DÉTERMINER AVEC EXACTITUDE LES GAINS ÉNERGÉTIQUES OBTENUS, LA RÉDUCTION DE CONSOMMATION D'ÉNERGIE A ÉTÉ APPRÉCIABLE.

LES PROGRAMMES GOUVERNEMENTAUX D'AIDE ET D'INFORMATION, LES MESURES FISCALES, LA RÉGLEMENTATION EXPLIQUENT À DIVERS DEGRÉS LES RÉSULTATS OBSERVÉS. CES RÉSULTATS SONT SANS DOUTE D'ABORD IMPUTABLES AUX RÉACTIONS PROVOQUÉES PAR LA HAUSSE RAPIDE DES PRIX DE L'ÉNERGIE. CHACUNE DES INTERVENTIONS EST VENUE RENFORCER LES AUTRES, ET IL EST IMPOSSIBLE DE DIRE CE QUI SERAIT ARRIVÉ EN L'ABSENCE DE L'UNE OU DE L'AUTRE. L'OBJECTIF DES GOUVERNEMENTS, QUI ÉTAIT D'AIDER LES CONSOMMATEURS À RÉAGIR À LA HAUSSE SUBITE DES COÛTS DE L'ÉNERGIE, A CEPENDANT ÉTÉ ATTEINT.

PAR AILLEURS, LE DÉVELOPPEMENT DES FILIÈRES ÉNERGÉTIQUES NON CONVENTIONNELLES A CONNU MOINS DE SUCCÈS ET, DANS LA PLUPART DES CAS, A ÉTÉ LIMITÉ AU NIVEAU DE LA RECHERCHE. LES COÛTS RELATIVEMENT FAIBLES DES ÉNERGIES CONVENTIONNELLES FONT EN SORTE QUE LE SEUIL DE

RENTABILITÉ EST DIFFICILE À FRANCHIR POUR LA PLUPART DES FILIÈRES D'ÉNERGIES NOUVELLES.

LA PERTINENCE DE POURSUIVRE DES ACTIONS GOUVERNEMENTALES DANS CE DOMAINE DÉCOULE DE LA VOLONTÉ D'AGIR EN FONCTION DE DÉVELOPPEMENTS À MOYEN ET À LONG TERME. MÊME SI ELLE DEMEURE ENCORE D'ENVERGURE RELATIVEMENT FAIBLE, IL EXISTE AU QUÉBEC UNE INDUSTRIE DES ÉNERGIES NOUVELLES SUSCEPTIBLE DE CONNAÎTRE UNE BONNE EXPANSION. PAR AILLEURS, LES TECHNOLOGIES RELIÉES AUX ÉNERGIES NOUVELLES PEUVENT COMPTER SUR DES MARCHÉS D'EXPORTATION POTENTIELLEMENT IMPORTANTS TANT, POUR CE QUI EST DES ÉQUIPEMENTS, QUE POUR CE QUI EST DES SERVICES ET DU SAVOIR-FAIRE QUI Y SONT ASSOCIÉS.

THE STEPS TAKEN BY THE QUÉBEC GOVERNMENT WITH RESPECT TO ENERGY ARE BASED ON FOUR MAIN GUIDING PRINCIPLES:

- THE PLANNING OF RESEARCH, TECHNOLOGICAL DEVELOPMENT AND DEMONSTRATION ACTIVITIES;

- CONSULTATION WITH THE PRIVATE SECTOR, BY MEANS OF TECHNICAL AND FINANCIAL SUPPORT, IN ORDER TO ENCOURAGE COMPANIES AND AGENCIES THAT ARE CAPABLE OF CONTRIBUTING TO ENERGY DEVELOPMENT;

- THE CARRYING OUT, BY SPECIALISTS, OF RESEARCH, DEVELOPMENT AND DEMONSTRATION;

- THE ADAPTATION OF ENERGY DEVELOPMENT STRATEGIES TO MEET THE SPECIFIC NEEDS OF TARGET CLIENTELES.

THIS IS AN OVERVIEW OF THE QUÉBEC GOVERNMENT'S ENERGY POLICY WITH REGARD TO ENERGY MANAGEMENT.

LE PROGRAMME D'AIDE AU DÉVELOPPEMENT DES TECHNOLOGIES DE L'ÉNERGIE

AFIN D'INTERVENIR DIRECTEMENT DANS LE DÉVELOPPEMENT DES TECHNOLOGIES DE L'ÉNERGIE, LE MINISTÈRE DE L'ÉNERGIE ET DES RESSOURCES DU QUÉBEC DISPOSE D'UN PROGRAMME D'AIDE AU DÉVELOPPEMENT DES TECHNOLOGIES DE L'ÉNERGIE.

CE PROGRAMME D'AIDE EST DOTÉ D'UN BUDGET ANNUEL D'ENVIRON 2,5 MILLIONS DE DOLLARS. CE BUDGET EST D'AILLEURS EN HAUSSE D'UN MILLION DE DOLLARS PAR RAPPORT À CELUI DE 1990, CE QUI DÉMONTRE, EN CETTE PÉRIODE DE RESTRICTIONS BUDGÉTAIRES, L'IMPORTANCE QU'ACCORDE LE MINISTÈRE DE L'ÉNERGIE ET DES RESSOURCES AU DÉVELOPPEMENT TECHNOLOGIQUE.

COMPTE TENU QUE LES ENTREPRISES ET LES GROUPES DE RECHERCHE SUBVENTIONNÉS CONTRIBUENT GÉNÉRALEMENT AU

FINANCEMENT DES PROJETS DANS UNE PROPORTION MOYENNE DE 50 %, LES SUBVENTIONS OCTROYÉES ENTRAÎNENT DES MISES DE FONDS DE PRÈS DE 5 MILLIONS DE DOLLARS PAR ANNÉE DANS LE DÉVELOPPEMENT DES TECHNOLOGIES DE L'ÉNERGIE AU QUÉBEC.

CE PROGRAMME D'AIDE PRIVILÉGIE LE DÉVELOPPEMENT DES TECHNOLOGIES RELIÉES À LA VALORISATION DE LA BIOMASSE, DE MÊME QU'AU DÉVELOPPEMENT DE LA FILIÈRE HYDROGÈNE. CEPENDANT, DES FONDS ONT ÉTÉ ATTRIBUÉS DANS PLUSIEURS AUTRES DOMAINES : ÉLECTROTECHNOLOGIES, GAZOTECHNOLOGIES, CARBURANTS DE SUBSTITUTION, ÉNERGIE SOLAIRE ET ÉNERGIE ÉOLIENNE.

DANS LE CADRE DE CE PROGRAMME, LES PROJETS CORRESPONDANT À DES INITIATIVES PROCHES DE LA COMMERCIALISATION PEUVENT FAIRE L'OBJET DE SUBVENTIONS DE L'ORDRE DE 25 % DES DÉPENSES IMPLIQUÉES, ALORS QUE DES PROJETS

PLUS FONDAMENTAUX OU À RISQUE TECHNOLOGIQUE PLUS ÉLEVÉ PEUVENT, DANS LA MESURE OÙ ILS PRÉSENTENT DES PERSPECTIVES D'APPLICATION INTÉRESSANTES, FAIRE L'OBJET DE SUBVENTIONS COUVRANT JUSQU'À 75 % DES DÉPENSES PRÉVUES.

LA CLIENTÈLE EST DIVERSE : UNIVERSITÉS, FIRMES-CONSEILS, CENTRES DE RECHERCHE PARAPUBLICS ET PRIVÉS, ASSOCIATIONS SPÉCIALISÉES, INDUSTRIES.

SUBSIDIES ARE AWARDED FOR:

- FEASIBILTY STUDIES;
- RESEARCH, DEVELOPMENT AND DEMONSTRATION OF TECHNOLOGIES, FACILITIES AND PROCESSUS;
- THE ACTIVITIES OF SPECIALIZED ASSOCIATIONS;
- STUDY AND RESEARCH GRANTS;
- THE FINANCING OF UNIVERSITY CHAIRS;

- THE FINANCING OF SPECIALIZED CONGRESSES AND SYMPOSIUMS.

THE PROGRAM IS THE CENTREPIECE OF THE DEPARTMENT'S SUPPORT FOR THE DEVELOPMENT OF ENERGY TECHNOLOGIES AND COMPLEMENTS THE STEPS TAKEN BY HYDRO-QUÉBEC AT ITS VARENNES AND SHAWINIGAN LABORATORIES, BY PROMOTING MEDIUM AND LONG-TERM TECHNOLOGICAL DEVELOPMENT.

MANY QUÉBEC COMPANIES, LIKE GAZ MÉTROPOLIITAIN, ARE ALSO EXPENDING CONSIDERABLE EFFORTS ON RESEARCH AND SEVERAL PROJECTS HAVE BEEN SUBMITTED TO THE FONDS DE DÉVELOPPEMENT TECHNOLOGIQUE, CREATED BY THE QUÉBEC GOVERNMENT IN 1989. THIS FUND HAS A BUDGETARY RESERVE OF $ 300 MILLION, WHICH CAN BE USED TO FUND TECHNOLOGIES RELATED TO SUSTAINABLE DEVELOPMENT.

DEPENDING ON THE TYPE OF RESEARCH AND DEVELOPMENT PROJECTS, AN ARRAY OF SUPPORT MEASURES EXIST THAT MAKE THE QUÉBEC GOVERNMENT A MAJOR PARTNER IN TECHNOLOGICAL DEVELOPMENT.

PERSPECTIVES D'AVENIR

J'AIMERAIS MAINTENANT VOUS FAIRE PART DU POINT DE VUE DU MINISTÈRE DE L'ÉNERGIE ET DES RESSOURCES SUR LES PERSPECTIVES QUE PRÉSENTENT LES ÉNERGIES RENOUVELABLES. JUSQU'À MAINTENANT, LE PRINCIPAL OBSTACLE À LEUR DÉVELOPPEMENT A ÉTÉ LA GRANDE ABONDANCE DE COMBUSTIBLES FOSSILES ET LES COÛTS RELATIVEMENT FAIBLES DES ÉNERGIES CONVENTIONNELLES.

OR, CETTE CONJONCTURE DÉFAVORABLE EST APPELÉE À ÉVOLUER. EN EFFET, LE PÉTROLE ET LE GAZ SONT DES RESSOUR-

CES NON RENOUVELABLES ET LEURS RÉSERVES SERONT TÔT OU TARD ÉPUISÉES. IL FAUDRA BIEN À LONG TERME, SE TOURNER VERS DES SOURCES ALTERNATIVES POUR SATISFAIRE NOS BESOINS ÉNERGÉTIQUES.

DE PLUS, LES PROBLÈMES ENVIRONNEMENTAUX PROVOQUÉS PAR LA CONSOMMATION DES COMBUSTIBLES FOSSILES, TELS QUE LES PLUIES ACIDES ET L'EFFET DE SERRE, DE MÊME QUE LES PRÉOCCUPATIONS CROISSANTES DU GRAND PUBLIC FACE À CES PROBLÈMES POURRAIENT BIEN ACCÉLÉRER L'AVÈNEMENT D'UNE VÉRITABLE INDUSTRIE DES ÉNERGIES NOUVELLES.

L'ÉVOLUTION DU BILAN ÉNERGÉTIQUE DU QUÉBEC AU COURS DES DERNIÈRES ANNÉES MONTRE QUE NOUS SOMMES PARVENUS À DIVERSIFIER NOS SOURCES D'ÉNERGIE ET À PRENDRE UNE CERTAINE DISTANCE PAR RAPPORT AUX CARBURANTS FOSSILES. DE PLUS EN PLUS, CHAQUE FORME D'ÉNERGIE DEVRA ÊTRE DÉVELOPPÉE ET EMPLOYÉE EN FONCTION DE CRÉNAUX

SPÉCIFIQUUES, BASÉS SUR DES AVANTAGES COMPARATIFS. IL IMPORTE DONC POUR LE DÉVELOPPEMENT DES ÉNERGIES NOUVELLES D'IDENTIFIER LE PLUS CLAIREMENT POSSIBLE LES USAGES POUR LESQUELS ELLES PRÉSENTENT DE TELS AVANTAGES.

WIND ENERGY IN QUÉBEC

AS YOU DOUBTLESS KNOW, THE DEVELOPMENT OF WIND ENERGY HAS GREAT POTENTIAL IN CERTAIN REGIONS OF QUÉBEC, SUCH AS THE GASPÉ PENINSULA, THE LOWER NORTH SHORE, ANTICOSTI ISLAND AND THE SHORES OF THE JAMES BAY AND HUDSON'S BAY. HOWEVER, THE ROLE PLAYED BY HYDROELECTRICITY IN QUÉBEC EXPLAINS WHY WIND ENERGY, ALONG WITH OTHER RENEWABLE ENERGY FORMS, IS ONLY MARGINALLY EXPLOITED.

TECHNIQUES FOR CONVERTING WIND ENERGY INTO ELECTRICITY ARE ALREADY BEING MARKETED FOR SMALL FACILITIIES. HOWEVER, WIDER EXPLOITATION OF WIND ENERGY IS BEING HAMPERED BY PROBLEMS WITH THE RELIABLITY OF EQUIPMENT.

IN ADDITION, LARGE-SCALE WINDMILLS DESIGNED TO BE CONNECTED TO ELECTRIC DISTRIBUTION NETWORKS ARE STILL IN THE DEVELOPMENT STAGE. ÉOLE, THE 4-MEGAWATT WINDMILL JOINTLY INSTALLED BY HYDRO-QUÉBEC AND SNC-LAVALIN AT CAP-CHAT, IS A MAJOR AND UNIQUE DEMONSTRATION OF THE POTENTIAL OF THESE INSTALLATIONS.

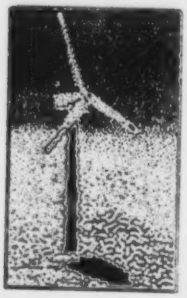
IT IS UNLIKELY THAT WIND ENERGY WILL CONTRIBUTE SIGNIFICANTLY TO QUÉBEC'S ENERGY SITUATION. HOWEVER, IT IS DESTINED TO PLAY A PROMINENT ROLE IN SUPPLYING ENERGY TO REMOTE COMMUNITIES. IN THIS RESPECT, PROJECTS TO BUILD WINDMILLS IN COMMUNITIES IN NOUVEAU-QUÉBEC, AS WELL AS WINDMILL FARMS COMBINED WITH DIESEL-POWERED

GENERATORS, ARE EXPERIMENTS THAT THE DEPARTMENT HAS EVERY INTENTION OF PROMOTING.

CONCLUSION

IN CONCLUSION, THE QUÉBEC GOVERNMENT ATTACHES GREAT IMPORTANCE TO RENEWABLE ENERGIES IN ITS ENERGY POLICY AND CONCRETE STEPS HAVE BEEN TAKEN TO IMPLEMENT THE GOALS OF THIS POLICY.

JE VOUS REMERCIE DE VOTRE ATTENTION ET JE VOUS SOUHAITE UNE BONNE FIN DE CONFÉRENCE.



TEST SITE ACTIVITIES

ATLANTIC WIND TEST SITE INC.

Carl Brothers
Site Manager
Atlantic Wind Test Site
North Cape, P.E.I.

INTRODUCTION

Since its establishment in 1980 as a national test facility for the testing and development of wind energy technology in Canada, the Atlantic Wind Test Site (AWTS) has worked closely with government and industry to develop the technology.

In response to changing requirements within the Canadian wind energy industry and to improve the productivity and cost effectiveness of the facility, the management structure of the site was recently reorganized. With the new organization and the accompanying financial committment of both federal and provincial governments, the facility is in a better position to play an increased role in the future development of the technology in Canada. Since the re-organization, a number of new and challenging projects have been initiated.

AWTS ORGANIZATION

Atlantic Wind Test Site Inc. is a wholly owned subsidiary of the Prince Edward Island Energy Corporation, a crown corporation of the government of Prince Edward Island. The present organizational structure of AWTS is indicated in Figure 1.

Funding is provided to AWTS from three sources. The federal government of Canada provides 80% of the core funding required while the provincial government provides 20%. AWTS Inc. pursues external project activity to supplement core funding. The federal government retains ownership of all assets of AWTS Inc.

With the recent addition of a research engineer, AWTS Inc. has five full time employees consisting of two engineers, two technicians and a secretary/accountant. In addition to full time staff, the services of several consulants are available to AWTS Inc. on an "as required" basis. AWTS retains the services of Island Technologies Incorporated (ITI) on a regular basis to assist in the management and operation of the site. The principal of ITI, Malcolm Lodge, has been affiliated with AWTS since it was established.

Technical direction is provided to AWTS by the AWTS Technical Advisory Committee (AWTS-TAC). The TAC is responsible for approving

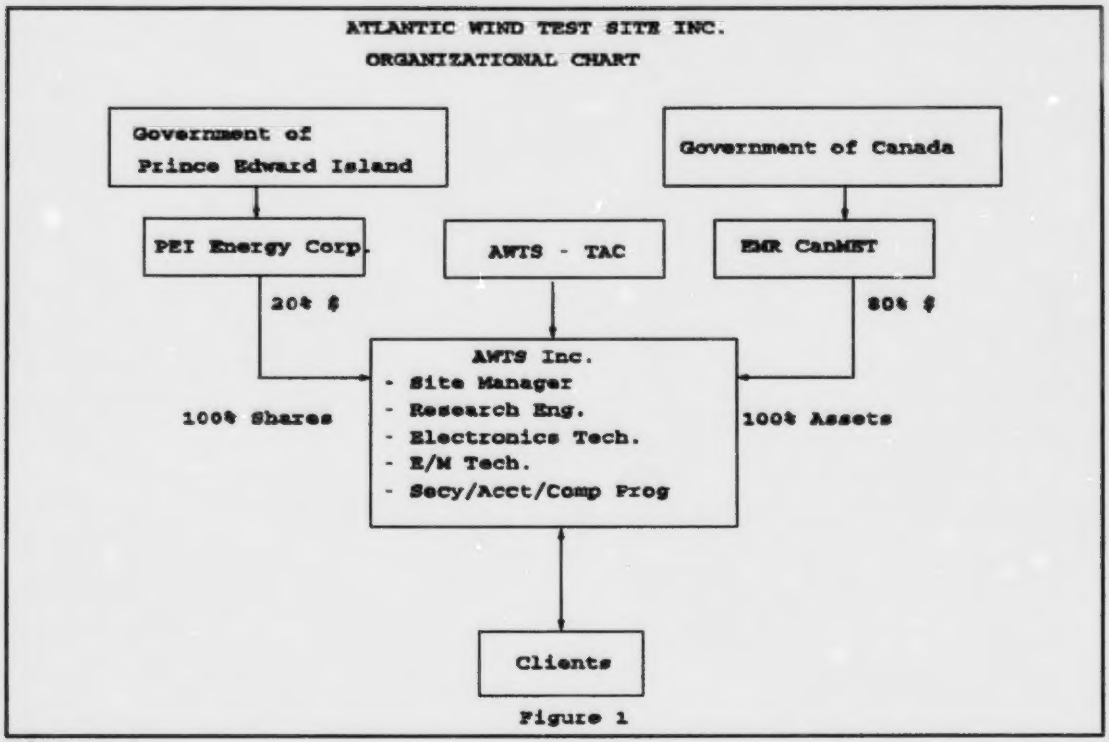

ATLANTIC WIND TEST SITE INC.
ORGANIZATIONAL CHART
Government of Prince Edward Island
Government of Canada
PEI Energy Corp.
AWTS - TAC
EMR CanMET
20% $
80% $
AWTS Inc.
- Site Manager
- Research Eng.
- Electronics Tech.
- E/M Tech.
- Secy/Acct/Comp Prog
100% Shares
100% Assets
Clients
Figure 1

Figure 1

all research projects carried out by AWTS staff. The TAC makes a critical contribution to the success of activities at the site. It reviews, and approves proposals, budgets and reports prepared by AWTS staff. It also provides direction and effective feedback to AWTS management and to funding agencies. This process enables AWTS resources to be directed to specific research or test program that the TAC considers appropriate.

Project activity at AWTS is categorized into internal or external projects. External projects are funded either totally or partially by their proponents. Funding for external projects may be supplemented by AWTS with labor or other assistance as directed by the TAC. Internal or "in-house" projects are funded from the AWTS core funding. These projects will be initiated and carried out by either AWTS staff or by collaborative researchers from universities, consulting firms or manufacturers.

SITE RESOURCES

As a development and testing facility, AWTS Inc. offers a number of essential resources to the Canadian wind energy community.

North Cape, exposed through 300 degrees to the Gulf of St. Lawrence, is subjected to high winds, large temperature variations, frequent icing events and a corrosive marine environment. The cumulative effect of these conditions is to provide one of the most extreme environments in the world for test stations evaluating wind energy technology.

Facilities to test grid connected as well as autonomous wind turbines, accomodations to house visiting engineers and scientists and state of the art monitoring and data acquisition systems provide AWTS with the capabilities and resources to carry out a wide range of test programs.

AWTS considers is staff as the most important resource it possesses. AWTS engineers and technicians have many years of experience in the testing and monitoring of wind turbines and bring their training and experience to each project undertaken.

SITE ACTIVITIES

AWTS has been active in a number of projects over the last year. Some of the projects have been a continuation of existing test programs while others have been initiated recently. A brief discussion of each project follows:

Aquilo

The 500 KW Indal VAWT has been in service at AWTS for eight years. AWTS continues to operate and maintain it and generate revenues from electricity sales to MECL.

Enertech

The E44-40 KW Enertech. This machine was moved to AWTS from a demonstration site where it operated for four years has been in service at AWTS for two years and has been operating in automatic grid connected mode.

AWTS has recently modified the grid interconnection wiring at the site to permit the Enertech to be operated in conjunction with the wind-diesel system. This option provides great flexibility to investigate operation of multiple wind turbines in small diesel grids.

AWTS has also installed an Enerpro Autosynchronous Controller on the unit to investigate operational effects of the unit in grid connected and wind-diesel applications. For grid connected applications, the low voltage operation in marginal winds is an attractive option while the low current start is an important consideration for wind-diesel applications. A report will be issued this quarter describing the result of the the Enerpro test in grid connected and wind-diesel applications.

Wind-Diesel

Wind-diesel activity has been receiving greater emphasis in Canada in recent years and considerable effort has has been devoted to wind-diesel activities at AWTS during the past year.

Modifications to the equipment have made the existing test bed much more versatile for wind-diesel test activities. The Indal 35 KW VAWT drive train has been modified to permit more reliable long term operation and with the Enertech 40 KW HAWT connected to the wind-diesel test bed, the operation of multiple wind turbines in wind-diesel applications can now be studied in detail.

A project carried out in early 1991 for Ontario Hydro investigated transients related to the connection of two induction generator equipped wind turbines to a relatively small wind-diesel grid. The project evaluated the connection of the two AWTS wind turbines to the diesel grid for a range of wind speeds and power level conditions using several different low voltage starting techniques.

AWTS has been conducting a comparative study of four wind-diesel models over the past several months and has released the report in draft form. Work on wind-diesel models will continue over the next coming months as the existing EMR wind-diesel model is further evaluated and optimized.

Electrical Demand Study

It has been known for many years that Prince Edward Island has a reasonable wind resource and that wind energy could make a substantial contribution to P.E.I.'s energy requirements. No work had been done, however, to investigate the correlation between the wind resource and the actual utility demand requirements in P.E.I. AWTS has recently concluded analysis on two years on contiguous data that compares actual system load data with projected wind energy supplied from a simulated wind farm using the wind resource measured at AWTS. The report will be issued in draft form by December 1991.

Wind Resource Assessment

A project to investigate the detailed wind resource at a number of locations in Prince Edward Island has been initiated this past year with the erection of four monitoring towers. The wind resource will be monitored for a one year period and the data analyzed. If the resource is adequate, interest has been expressed in the development of a commercial wind farm.

In addition to the acquisition and analysis of the wind data, this project will develop a Wind Resource Assessment and Siting Guide. This publication will describe wind resource assessment methodology for wind energy projects.

Icing

AWTS has been pursuing potential collaborative research activities with universities since it was reorganized. To assess the practicality of performing such collaborative research, a pilot project was initiated with Memorial University of Newfoundland (MUN) to investigate the effects of icing on wind turbine blade performance. In this project a graduate student from MUN who had studying the effects of icing on wind turbine blades for several years in wind tunnel studies came to AWTS for several weeks in the hope of witnessing an actual icing event on an operational wind turbine. Tests were also conducted to determine whether icing events could be realistically simulated using conventional spray technology. The test project resulted in a paper published in an international aeronautical journal and agreement from both parties that collaborative research into generic areas of interest was a valuable exercise. AWTS will continue to collaborate in wind energy research with other academic organizations in the future.

Information Transfer and Public Awareness

AWTS continues to participate in the transfer of wind energy related information to interested people.

- 11,000 visitors were received during the summer of 1991 at North Cape's tourist information centre.
- Technical information was also provided to numerous additional requests.
- The upgraded AWTS Fact Sheets on wind energy which provide technical information to the public on the technology were released to the public this summer.
- AWTS hosted numerous school tours and several "Young Environmentalist" seminars.

Certification

As Canada's national testing facility for grid connected wind turbines, AWTS expects to play an important role in certification programs established in Canada. Certification programs exist in Denmark and the Netherlands where the use of wind energy is more common than in Canada. It is anticipated that with the increase in the popularity of wind energy in Canada, the need will arise for such programs here as well.

To respond to this eventuality AWTS has initiated a project to study certification programs existing in other countries and to propose a certification procedure for Canadian application.

FUTURE ACTIVITIES

For the coming year, AWTS will continue to work on the projects described above until they are brought to a conclusion. AWTS has also initiated activities on several other projects that are expected to commence this fall.

AWTS staff will install and determine the operational and performance characteristics of an innovative wind turbine developed by Adolph Duesterhaus from the NorthWest Territories. This drag type turbine according to Mr. Dusterhaus offers advantages over conventional drag type turbines. This project will be supported by the Science Institute of the NorthWest Territories.

AWTS has submitted a collaborative proposal with Hydro Quebec to carry out a demonstration program, using the AWTS wind-diesel test bed, to study the High Penetration No Storage Wind-Diesel (HPNSWD) scenario developed at IREQ several years ago. This project is a comprehensive wind-diesel development and demonstration project and has attracted considerable interest in discussions with international colleagues. If the results from the study confirm expectations, the HPNSWD strategy will place Canada at the leading edge of wind-diesel development and market penetrations.

AWTS has also proposed the installation and evaluation of several additional wind turbines that would be evaluated for eventual deployment in remote communities and would also be utilized in the proposed AWTS/IREQ wind-diesel proposal. It is anticipated that the installation of these turbines will commence in the fall of 1991.

Several manufacturers of micro machines have agreed to supply some of their turbines to AWTS for a one year testing and evaluation program. The purpose of this program is to obtain operating experience with these small units that are so popular with visitors to the AWTS tourist center and to provide some exposure for the manufacturers to these interested people.

AWTS will host the annual AWEA-CanWEA wind-diesel workshop in June 1992.

Preceding the wind-diesel workshop AWTS will present a wind energy seminar for interested groups or individuals such as government or educational, interested in learning about the basics of wind energy.

Interest remains high within AWTS Inc. to continue developing collaborative research projects with interested research institutions. Several areas have been targetted for establishing contacts and efforts will be made in the coming year to pursue these options further.

CONCLUSIONS

The organizational changes that AWTS Inc. has implemented in the past year are key for the site to play a constructive role in the development of wind energy technology in Canada. Other important changes have also been implemented that will contribute significantly to the new role of AWTS.

- Funding levels have been committed by both federal and provincial governments that enable AWTS to pursue productive activities.
- With the removal of AWTS from the routine proposal process, other participants are likely to view AWTS more as a resource than a competitor.
- Most importantly has been the committment to technical review that has been added to the process. Long term technical planning can now be implemented within the present structure. This will greatly enhance the effectiveness of the site.

It has been some time since optimism has permeated minds and attitudes within the Canadian wind energy community. However with the emerging environmental awareness and the growing support of renewable energy worldwide, it seems inevitable that Canada will eventually follow in its suppport of wind technology. The recent re-establishment of funding and reorganization of AWTS Inc. has initiated optimism at AWTS for the first time in some years. Finally, AWTS has been given the tools with which to participate in the development of the technology in a productive manner.

For presentation at the Canadian Wind Energy Conference Windpower '91
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THE TEST STATION FOR WIND TURBINES AT RISØ. PROGRESS AND ACTIVITIES

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Abstract

The paper is based on the latest Risø progress report for the Test Station. The paper outlines the background and main scopes for the Test Station and proceeds to describe the activities within R & D, Certification of Wind Turbines, Testing and International Activities including Consultancy Assistance. The paper also contains a list of publications from the Test Station for 1990.

1. INTRODUCTION

The objectives of the Test Station for Wind Turbines are to contribute to the development of wind power technology, to evaluate and certify the safety, performance and technical solutions of wind turbines in Denmark, and to be a center of wind power technology. The target group for The Test Station consists of the wind turbine industry, the public authorities or agencies, and the users and the planners of the technology. The activities fall in four categories:

1. Strategic and applied research within the departments research themes Wind Resources and Wind Loads, Aerodynamics, Wind Power Technology and Tests and Measurements. The research is carried out in order to acquire and systemise knowledge relevant to wind energy and wind turbine technology and develop the theoretical tools necessary to advance the art.

2. Certification of wind turbines with the aim to secure their safety and documentation of quality. The certification of wind turbines for the Danish market is performed under contract with The Danish Energy Agency, whereas certification of export wind turbine projects is carried out on commercial terms.

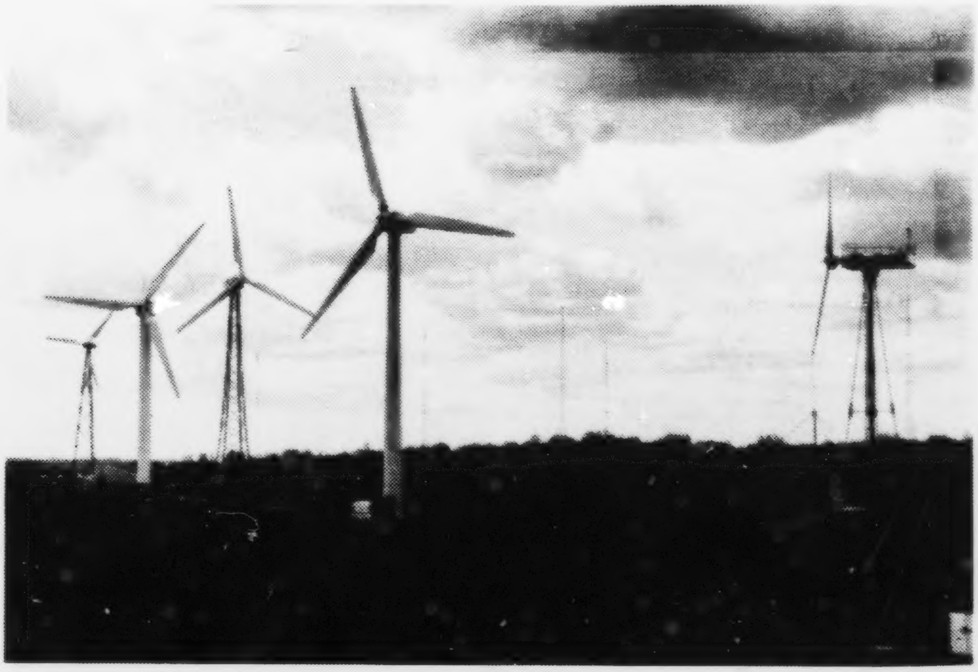

Fig 1. A view of the wind turbines at Risø Test Station 1990. From the far end:

- *Tellus 100 kW : EC founded HAWT project.*
- *DWT 430 kW : EFP founded active control project.*
- *Nordex 250 kW : Certification testing.*
- *Bonus 300 kW : Function test of Combi System.*
- *Risø 20 kW : Research WTG, 2 bladed configuration.*

The total installed power is 1.1 MW.

3. Testing of wind turbines and of major components (e.g. wind turbines blades) for certification purposes. Measurements of wind loads and wind turbine response and behavior at the test station or in the field are performed for research and development purposes.

4. Dissemination of information to the industry, international cooperation on standardization, test and certification procedures and consultancy assistance to authorities, government agencies, electrical utilities and other planners and users of wind power.

The common theme at The Test Station being wind power the technical background of the staff covers several scientific and engineering disciplines. The disciplines range from wind characteristics, aerodynamics and fluid dynamics, structural mechanics and dynamics to control theory, signal analysis, measuring techniques as well as machine design and electrical power systems. Especially aerodynamics and dynamics of flexible structures are treated as strategic research areas.

The significance attributed to aerodynamics as a basic research topic at the Test Station is illustrated by an ongoing Ph.D. project. In the project numerical methods for the prediction of the 3-dimensional separated flow are developed in order to supplement the earlier primarily experimental aerodynamics research at the Test Station.

The results of the Danish wind power community and the fruitful dialogue and interaction between the Danish wind turbine industry and the Test Station for Wind Turbine is the subject for another Ph.D. study. The project analyzes innovation processes and the interaction between research institutions and the industrial development. Insight from the project may provide guidance for future collaboration with the industry.

Some of the major projects or activities are presented below. The description follows the four main categories of work. A list of publications from the Test Station in 1990 is attached as references.

2. RESEARCH AND DEVELOPMENT

2.1 Aerodynamics

The short term goals for the aerodynamic research is to identify and quantify 1) instationary effects caused by turbulent inflow, yaw error, wake from other turbines and wind gradient, 2) three dimensional flow effects, 3) rotational effects and 4) scale effects. The problem has been treated both theoretically and experimentally.

The experimental investigations of rotor aerodynamics has to a large extent been based on the measurement results from the specially instrumented Tellus turbine. On this turbine a special blade is mounted which allows direct measurement of differential forces at three radial stations and local inflow characteristics. An important verification, as earlier investigations has indicated, is that high lift coefficients during stall are obtained at the inboard sections of the blade.

Detailed studies of the flow input and correlation to aerodynamic loads has been possible. The flow measurements corresponds to the turbulence spectrum seen by the rotating blade, and this is also an important intermediate result for verification of the calculational methods. The relation between flow input and aerodynamic load response determines the importance of unsteady aerodynamics. During operation corresponding to unseparated flow the unsteady effects are small, predictable from existing theory and close to the steady lift curve. However in stall the relationship is much more complex and stall hysteresis occurs.

The investigations of stall has revealed a new stall phenomena entitled "stall-shift" due to the fact that some profiles have two stable lift levels within a certain range of angles of attack. This is a boundary lager phenomena probably coupled to three dimensional effects and causes a similar unwanted shift in maximum power output.

2.2 Design Loads and Design Methods

The work within the area design loads and structural dynamics has concentrated on a better description and prediction of the dependency of the loads on turbine dynamics, control principle and wind parameters. An important result has been a theoretical work and verification of methods for dynamic tuning for optimization of wind turbines. It was found that cyclic rotor loads by proper choice of natural frequencies can be reduced by up to 50% compared to typical values for existing turbines.

Other results are related to loads on wind turbines in stall, in the wake from other turbines and on pitch regulated wind turbines.

In general there is good coincidence between measurements and predictions of cyclic loads at wind speeds before stall. An interesting new finding is that also in stall it has been possible to predict the principal change in frequency response spectrum.

2.3 Concepts and Applications

Within the investigation of new concepts, work has concentrated on development and verification of an aeroelastic model for two-bladed rotors with teetering hub. The model has e.g. been able to describe the yaw stability which is a complicated but critical point for such turbines. Another finding is that it is possible to reduce the loads compared to the three-bladed "Danish type". Whether this will lead to better overall economy is so for not revealed. Further work on verification is related to investigations using the Research Turbine, where several parameter variations are possible.

Also within application of wind power The Test Station has reached a mile stone in 1990. The wind-diesel work has by the end of 1990 terminated a phase in technological development, where the concept has been demonstrated and established on an applicational level. The following tasks has been terminated a) establishment of a wind-diesel test facility including an experimental system of simple self controlled design, b) demonstration, test and model verification on Risøs simple system and the more advanced system with battery storage, and c) development of a PC-based logistic simulation model for prediction of fuel savings, supply capacity and thereby economy. Coming mile stones will concentrate on development of tools for optimization.

3. CERTIFICATION OF WIND TURBINES

Since 1981 The Test Station for Wind Turbines has been responsible for the Danish certification of wind turbines under contract with the Danish Energy Agency. The certification was until 1989 linked with the subsidy to renewable energy, but in 1990 a law was passed in the Danish Parliament, giving the Minister of Energy the right to require that all wind turbines installed in Denmark have to be certified. Throughout 1990 work has been carried out on preparing the procedures and technical rules for a new certification system. Due to an election in December the starting date for the new system has been postponed until spring 1991.

In preparation for the coming system the an engineer and a technician were hired to the certification group which moved into new offices.

The need for more extensive blade test facilities was solved by renting a test faciiity in Sparkær in Jutland. The facility has capacity for both static and dynamic blade test, and has been operated by the Test Station for Wind Turbines since July 1990.

Static and dynamic blade tests were earlier tested in The Test Stations workshop, where blades up to 12m could be tested statically and dynamically. In 1990, though, the blade testing at Risø was stopped as The Test Station acquired The Sparkær Centre in Jutland for blade testing. The new certification system requires tests to be carried out independently from the certification group, and therefore blade testing was put under the responsibility of the testing group.

The Sparkær Centre was established in 1985 to develop blade technology for the wind turbine industry. The main facilities at the Centre are a static test rig in the workshop and an outdoor dynamic test rig which is covered by a tent that can be heated up. The facilities include a laboratory for analysis of glass fiber materials, workshops for construction of glass fiber parts and for mechanical tooling of materials. The Centre also has educational facilities with audio-visual equipment. It is the intent to expand the activities at the center in the future to utilize the actual facilities and to use the advantage of being closer to wind turbine manufacturers in Jutland.

Under the old certification system 10 general type certificates and 16 prototype cerficates were issued in 1990. The wind turbine types are rated from 150 kW to 450 kW with rotor diameters of 24-35 m.

In addition to the wind turbine testing at the Test Station 6 field tests were initiated in 1990 as a requirement for the certification. The tests were carried out by external consultants and funded by the Danish Energy Agency through Risø. The main purpose of the tests was a verification of power curves and air brake efficiency. Four tests have not been completed.

In 1990 a state-backed export finance guarantee was established. For a project to be eligible, the project has to be certified, ultimately according to the planned certification system. The first project comprising 342 Vestas 225 kW turbines for USA was certified in December.

4. TESTING

4.1 Wind Turbine Testing

Two new major test activities were started up at The Test Station in 1990. The first one was the testing of a Windane 34, 400 kW wind turbine from Vestas, and the other is the testing of a Bonus Combi, 300 kW wind turbine from Bonus.

The Windane 34 was erected on the large universal foundation at test pad 4 in March 1990. An adaptor was made to fit the tower to the foundation, and a transformer was set up to transform the voltage level from 660V to 380V, which is the grid voltage at The Test Station. The test plan includes basic measurements and measurements of several loads on the rotor, and loads in the top and bottom of the tower. Measurements of parameters in the pitch regulation mechanism and in the electronic control system is part of an R&D project, described elsewhere. Measurements were carried out throughout 1990 and continues in 1991. When the measurements at The Test Station has ended in June 1991, the wind turbine will be erected in the Kappel wind farm, and the measurements will continue at the site.

The Bonus Combi was erected at test pad 2 in July 1990. A new foundation that is able to take 500 kW wind turbines was made and a new 500 kW transformer was installed for grid connection. Measurements of power production were made for several different configurations. A final configuration with a conical tower and 14.2m LM blades was instrumented for basic measurements and measurements of several rotor and tower loads. Specifically, load measurements on the blade tips was emphasized early in the test period.

On test pad 3, a Nordex 250 kW wind turbine was erected in 1989 for a test of basic characteristics and rotor and tower loads. The rotor loads in tilt and yaw were specifically interesting because they could be measured directly on the gearbox stud that carries the rotor bearings. When the measurements had ended, problems occurred on the Windfoss blades in the autumn 1990, and the wind turbine was stopped until new blades were produced by LM-Glasfiber for a continued test.

The test pads 1 and 5 were used exclusively for research projects, described elsewhere.

4.2 Loads for Wind Turbines in Inhomogeneous Terrain

A large measurement program was carried out on two Danwin 23 wind turbines in California from April to August 1990. The purpose of the project was to find climatologic parameters for design input for wind turbines in inhomogeneous terrain and to measure actual loads on two wind turbines at selected sites in a wind park. The measurements were carried out in two steps.

The first measurements were carried out on a wind turbine in the front row of the wind farm with steep hill sides in front of the turbine. A meteorology mast was erected in front of the wind turbine with sensors at four levels. Parameters that was measured was horizontal and vertical wind speeds, air temperature and pressure. On the wind turbine five load parameters was measured on the rotor and five load par- ameters was measured in the tower. The measurements were carried out in May to June in which period the wind conditions showed up to be the best for the whole year.

The other measurements where carried out on a wind turbine in the middle of the wind park. The measurements were carried out from August to September 1990 and the parameters that were measured were almost the same as on the first one. The wind speeds in this period were much less, but an equal amount of data was recorded.

Preliminary data analysis of the measurements show that a significant and valuable data base for analysis of the wind climate and loads on stall-regulated wind turbines in wind parks in inhomogeneous terrain was gathered. Detailed analysis of the measurements will be carried out in a continued project.

5. INTERNATIONAL ACTIVITIES AND CONSULTANCY ASSISTANCE

The European cooperation of wind energy test stations ECWETS has continued its work for ECE-DG-XVII on the preparation of recommendations for wind turbine standards. During 1990 the Test Station has participated in work on the subject of Design Loads. The recommendation will be finished early 1991.

The IEC-work on the preparation of a standard for Safety of Wind Turbine Generators has continued in 1990. The working group one has with the participation of The Test Station prepared a draft standard for Safety Philosophy which has been sent out for comments. Furthermore the Test Station has participated in expert group meetings arranged by the International Energy Agency (IEA).

As part of the international consultancy assistance the Test Station has participated in a Danida feasibility study in 1990 concerning the possibilities for development of manufacture and application of wind turbines in Egypt.

A Danida project including the installation of a demonstration wind farm and a test station in Egypt is now being carried through by the department with participation from the Test Station.

In 1990 a new activity was started up with the wind turbine manufacturers on consultancy basis. This activity is verification of the manufacturers own measurements. The verification includes verification of measurement procedure, siting, measurements, analysis and reporting. One verification of a measurement was finalized in 1990 and three others were initiated.

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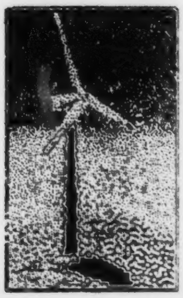

WIND/DIESEL ACTIVITIES

DYNAMIC MODEL OF A HIGH PENETRATION NO-STORAGE WIND/DIESEL SCENARIO

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ABSTRACT

The last decade has seen great progress in wind turbine technology, both as regards reliability of the machines and their associated automatic control systems. In Quebec, wind energy offers a particularly interesting means of reducing the energy costs for isolated communities. HYDRO-QUEBEC has been working for several years on developing simulation models involving the use of wind energy, with a view to predicting the technico-economical feasibility of High Penetration No-Storage Wind /Diesel scenario (**HPNSWD**). However, the quality of the energy produced is a dominating concern for HYDRO-QUEBEC. Voltage and frequency stability, as well as a clean harmonic free voltage, are fundamental requirements which need to be optimized. The integration of wind turbines into autonomous grids must not degrade the existing power quality. The general feasibility of **HPNSWD** systems has been demonstrated on a 50 kW model in operation at IREQ, Varennes. Results of a small scale simulation permitting the prediction of the principal mechanical and electrical parameters are presented. The simulation has been based on the use of the **EMTP** code (ElectroMagnetic Transients Program), with the calculation validated on IREQ's hybrid wind-turbine diesel test bed at Varennes.

Background

The IREQ wind-diesel project began five years ago. The first step was to demonstrate the economical benefit of the addition of wind generators in small northern community grid supplied by diesel generator sets. A computer algorithm based on one-hour simulation step was developed to estimate the fuel savings over one year of operation. Three scenarios were considered (fig 1).

1- Low penetration:

In this scenario, the installed wind generator capacity never exceeds 20-40% of the peak demand. This means that at least one diesel stays always in operation and the grid frequency is imposed by the diesel speed governor.

2- High penetration with storage

The second alternative consist of installing enough wind power capacity to fulfill all of the demand (shutdown of all diesels). This scenario involves the use of a storage device to filter the variable wind generator power. The storage system is responsible for maintaining a constant grid frequency. To be energy efficient, this system uses a battery bank associated witch sophisticated high-power electronic static converter. This technology is rather expensive at the moment. With this system, the system control is based on the reliability of batteries. Also , as the high-power inverter has not been extensively tested on a remote utility grid, its future use will depend on long term reliability tests.

3-High penetration without storage

In this scenario, priority is given to the free wind resource. The diesel motors can be stopped when the average wind energy production is at a certain level above the demand. The optimal wind penetration (wind capacity /peak demand) depends on the village characteristics (wind, price of fuel, type of diesels, value of the excess energy). This strategy requires the use of a dump load to dissipate the excess power between the production and the demand. This "rejected" energy has a value since it can be used to replace heating fuel. This controllable dump load is used to keep the grid frequency constant when production exceeds electrical demand.

Selected scenario:

The last scenario is technically more interesting for remote northern villages where the winds are strong, the price of fuel is high and the heating demand is large. The dump load turns out to be more reliable than a storage device and the installation of additional wind turbines is quite simple (modularity and short installation time). The economic benefit of wind is achieved when all the energy it has produced is put to an end. For this reason, the excess wind energy of scenario 3 could be dispatched to, for example, an hospital heating boiler primary operated with fuel simply by adding electrical elements. In this case, the economic value of dumped energy would be the cost of displaced fuel.

Technical feasibility of the High-Penetration No-Storage Wind/Diesel Scenario (HPNSWD)

Test bench of IREQ

IREQ Wind/diesel testing facility was devised around an INDAL 50kW Darrieus wind turbine (fig. 2). A 30 kW diesel genset was then added. The genset was modified to accommodate an unidirectional mechanical coupling between the motor and the alternator. This was necessary to maintain the grid voltage and reactive power requirements for the induction machine of the wind turbine when the diesel engine is turned off.

A 34 kW three-phase dump load was built. Its electrical elements are arranged in a binary progression and are switched with zero-crossing solid-state-relays. This structure permits the elimination of the harmonic problem associated with phase control strategy.

The dump load elements combination is controlled by an electronic board including a crystal based frequency reference. The phase error between the actual grid frequency and the reference is obtained by using a specially designed synchronous saturation phase detector. The error signal is processed through compensation circuit, converted through an analog to digital converter that triggers the electronic dump load relays. The phase control strategy was preferred over the simple frequency feedback. The phase detector will keep the frequency as precise and stable as the quartz reference is when working in a unsaturated state. In fact, the dump load and the electronic circuit are a large phase lock loop circuit (PLL).

The test facility of IREQ represent a worst case situation: The wind characteristics of the site are far from ideal; the vertical wind turbine produces a power ripple at twice its rotational speed (in a real situation, a number of wind turbines would produce a much less variable power output); in addition, the induction generator capacity exceed the alternator characteristic. The use of a soft-start equipment was absolutely necessary in this installation.

Software development

A numerical algorithm was developed to demonstrate the technical feasibility and robustness of a dump load phase regulator (PLL). The process involves the resolution of a set of linear differential equations representing the power to frequency characteristics of each component. The resulting schematic bloc is presented in figure 3. To run this software we need to identify components of an highly non-linear system around many operating points. Parameters identification tests have been done on the test bench equipment of IREQ. We explored and developed a new testing method. Finally the numerical process converges to a stable solution, calculating the optimum PID parameters around the nominal operating point (fig. 4).

These estimated PID characteristics calculated were used as initial values in the regulator associated with the testing facility at IREQ. On October18 of last year, we proceeded to conclusive tests that demonstrated the feasibility of our regulation strategy. It was demonstrated experimentally that, the diesel motor being stopped, the system maintains a stable frequency, while satisfying the demand of consumer load and using the dump load to absorb wind energy in excess of demand. The experimental curves are described in the following section.

Development and validation of a HPNSWD design tool

The software model based on linear differential equations presented in last section is not applicable for preliminary estimation of a project since the inputs of that software includes parameters that are generally not available in a catalog and than have to be identified by special identification tests. Also, this linear model is limited to the power flow calculation. This numerical tool will be useful for the final tune up of an existing layout. For wind/diesel retrofit design purposes, we looked for a tool that calculate the instantaneous evolution of voltage and current, to estimate real the incidence of wind generator on the quality of the energy produced and delivered to the grid.

The most used and adapted software for this micro-second step analysis is EMTP (ElectroMagnetic Transients Program , fig. 5). This software is largely supported by utility companies over the world. EMTP program solves non-linear problems. It includes all the subroutines for modeling all the components existing in the wind/diesel scenario. The difficulty is to understand the relationship between the system elements for generating the most representative "template" in EMTP parlance (parameter inputs of EMTP). Those parameters are the values found on component nameplates. Generally, these values are directly available from manufacturer without any additional test being required for their representation. The EMTP template schematic of IREQ test bench is presented in Figure 6.

The diesel is represented by a current source whose value is proportional to the throttle position. This current source is adjusted to maintain the voltage (electrical equivalent of the rotational speed in the electrical circuit representation) across a parallel resistor (friction) and capacitor (inertia) at a referenced value (that of the speed governor). The unidirectional coupling is modeled by a diode connected to the friction and inertia of the alternator. The alternator and induction machine are predefined EMTP modules. The alternator voltage regulator is also represented. The mechanical equivalent of the windmill rotor is converted to an electrical representation. The aerodynamic torque is shown as two current source whose value are extracted from a file. The dump load and the associated zero-crossing solid-state-relays are modeled using power switches latched at a voltage of zero. The dump load governor including the PID regulator is modeled with the DIGITALLY SIMULATED ANALOG COMPUTER EMTP MODULE (TASC).

For illustrating the validation and the use of this tool, we present the existing experimental setup at IREQ for which experimental data of transient tests are available.

Diesel as a production unit regulated by the dump load.

This reduced configuration of the system consists of using the diesel as a power source feeding the dump load. This test is purely academical, because dumping fuel energy does not have a great practical interest. But this configuration is very interesting for verifying the correct operation of the regulator. It can be part of multi-testing procedure for the qualification tests of a new equipment. Figure 7 presents the EMTP template schematic for this particular layout. The speed governor and the windmill model are removed, the throttle is mechanically blocked in such a way so as to produce some over speed (relative to the dump load regulator reference frequency). In this condition with small speed deviation, the motor acts as a torque source feeding the alternator.

On the electrical side, the dump load regulator attempts to maintain a constant 60 Hz frequency by dissipating excess energy. A step increase in demand (less than the initial dumped power) is switched on, and ,1.5 second later, off. The step in power demand corresponds to one third of the installed alternator capacity. This testing condition is very severe. The predicted and experimental results are presented in figures 8a to 8f.

Figure 8a presents the EMTP demand and dump load power predictions. We can see that a step increase in demand is quickly detected by the dump load regulator. It responds by reducing the dump power by the same amplitude for maintaining the frequency and the power equilibrium. Figure 8b show the experimental result. We observe that the curves are very nearly those presented in figure 8a. On figures 8c and 8d showing predicted and real diesel power, it can be seen how fast the dump load regulator responds. Simulated and experimental results again are very close. Those four figures (8a to 8d) demonstrate the accuracy of EMTP tool. Figure 8e presents the phase error coming out from the specially design phase comparator. The electronic regulator detects an increasing phase error caused by an overload of the alternator (fig 8c and 8d) whose speed drops instantly upon application of a step in demand. The phase shift causes the reduction of the amount of dumped power to re-establish the equilibrium between production and demand. We observe that the phase signal is unsaturated , varying from -180 (0) to +180(1) during the demand transient. This means that the precision of the grid frequency should be kept very stable and will depend essentially on the precision of the quartz reference itself.

Looking at the voltage waveform (Figure 8f), we observe that they are free of harmonics. The zero-crossing relays introduce no harmonics and no additional filtering devices are required.

Simulation of a complete high-penetration no-storage wind /diesel system.

With the diesel stopped, the windmill producing an average of 20 kW , a 12 kW grid demand is switched on and off and power measurements going to the dump load are taken. Figure 9a to 9f show the simulated and experimental cases for this situation.

The demand and dump load power curves are shown on figure 9a. We observe the consequences of the high torque ripple of the Darrieus machine at twice its rotational speed. In our case, the frequency of this ripple is 2.66 Hz and varies by +- 20 % including the filtering effect of the mechanical inertias. The demand step is approximately flat, the dump load regulator responds quickly . Figure 9b present experimental results obtained last year (10/18/90). The test condition are near those selected in the simulation process. We can observe the similitude between simulation and real data

Figure 9c shows the induction generator power. Like the case of the diesel alone, we see the response time of the regulator that maintains the power equilibrium.
The phase error illustrates the correct behavior of the phase lock loop (figure 9d).

The alternator current wave form is presented in figure 9e (note that the diesel is stopped). This reactive current is the one that supply the reactive power of the induction generator. The reactive power ripple is a consequence of the active output power fluctuation of the induction machine. This curve and the grid voltage wave form of figure 9f demonstrate the correct operation of the alternator voltage regulator and the good power quality delivered to consumer.

The results are conclusive and validate the prediction of EMTP software.

Importance of the voltage regulator dynamics

The alternator voltage regulator responds to the impedance fluctuation across the terminals. If the voltage governor is slow, then the dump load regulator has to be very fast to eliminate interaction between itself and the voltage regulator. The EMTP software can help us in the selection of good AVR (Automatic Voltage Regulator).

Conclusion

Software tools to predict the exact operating conditions of a high-penetration no-storage wind/diesel system has been developed and validated. This tool can help to evaluate the effect of wind generators and regulator characteristics on the quality of the power produced.

During the last five years, Hydro-Québec has managed to demonstrate the technical feasibility of the high-penetration no-storage wind/diesel scenario at its experimental test site. Tools and practical experience have been developed that support the validity of this scenario and its use in remote northern communities with diesel gensets. However, the operation group of remote community networks feel that, due to a lack of demonstrated reliability of such a system, its implementation in a real village remains dubious for the near future.

Future prospects

Before a full size demonstration project (multiple diesel and multiple wind turbines) is built and operated over a representative period, it is very unlikely that this type of system will be implemented in remote networks. Discussions on a project aiming at the installation of a representative system are presently initiated between the Atlantic Wind Test Site, Energy, Mines and Resources Canada and Hydro-Québec. Its objectives are to obtain long term data to validate control strategies and their effect on fuel savings for the high-penetration no-storage wind/diesel scenario. Such a project should be a major achievement in this technology in Canada and on the international scene as well, since no system of this type presently exists while the market where it is applicable is very large. This project could also attract organizations from Denmark and the US involved in the promotion of simple reliable wind/diesel scenarios.

Figure 1

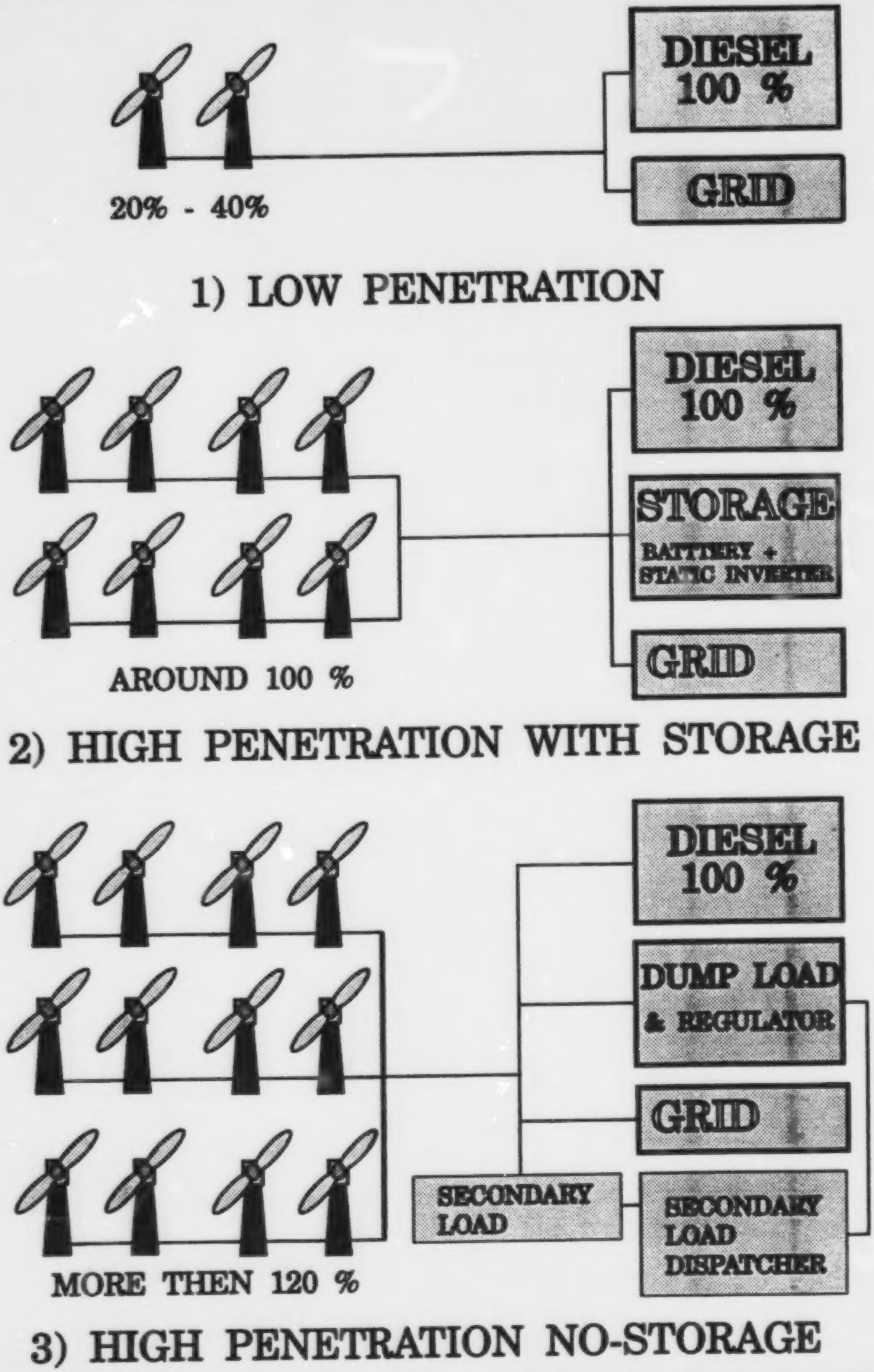
DIESEL 100 %
GRID
20% - 40%
1) LOW PENETRATION
DIESEL 100 %
STORAGE
BATTTERY +
STATIC INVERTER
GRID
AROUND 100 %
2) HIGH PENETRATION WITH STORAGE
DIESEL 100 %
DUMP LOAD
& REGULATOR
GRID
SECONDARY LOAD
SECONDARY LOAD DISPATCHER
MORE THEN 120 %
3) HIGH PENETRATION NO-STORAGE

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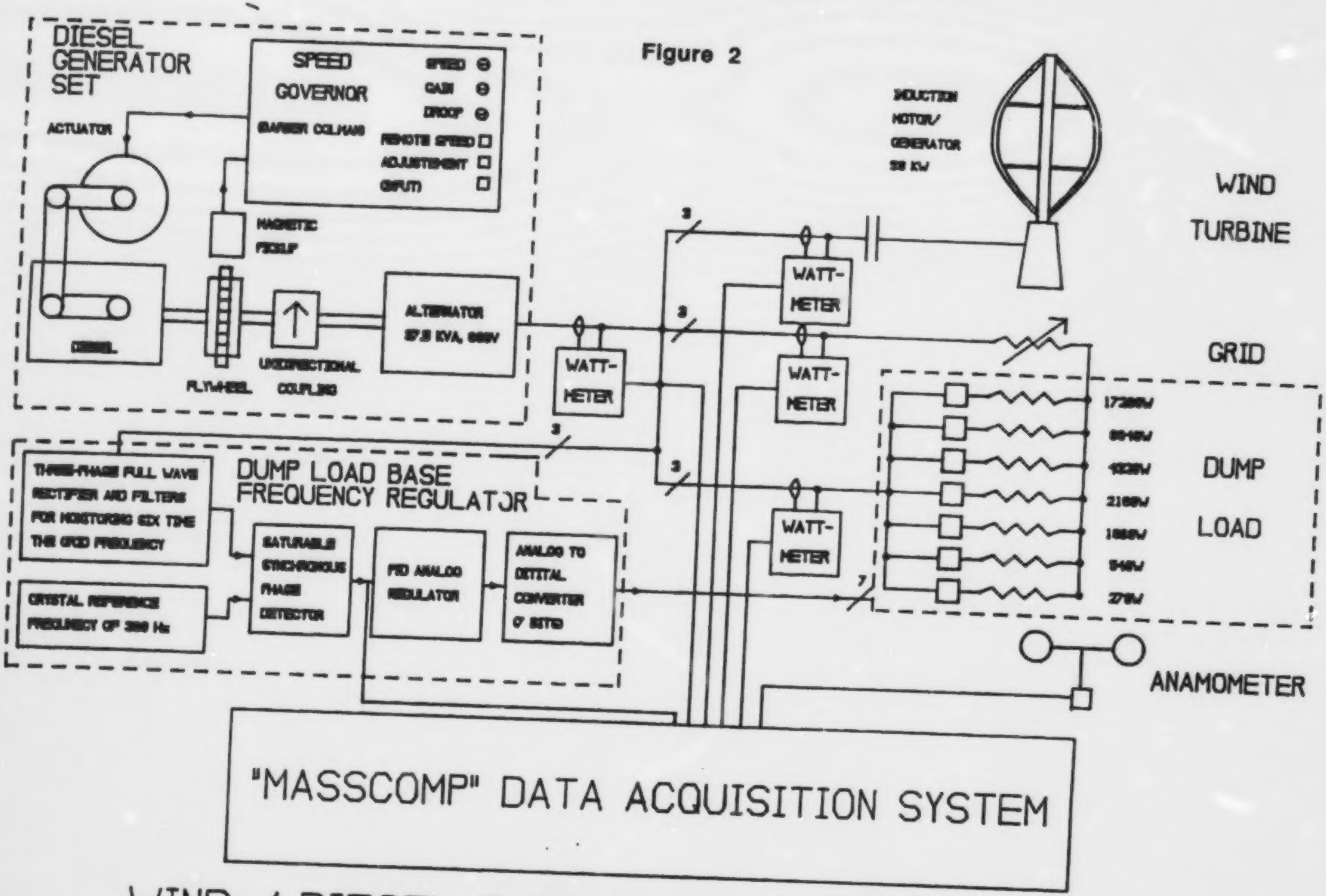
Figure 2


DIESEL GENERATOR SET
ACTUATOR
DIESEL
SPEED GOVERNOR
BARBER COLMAN
SPEED
GAIN
DROOP
REMOTE SPEED
ADJUSTEMENT
(INPUT)
MAGNETIC PICKUP
FLYWHEEL
UNIDIRECTIONAL COUPLING
ALTERNATOR 37.5 KVA, 600V
WATT-METER
WATT-METER
WATT-METER
WATT-METER
3
3
3
3
7
INDUCTION MOTOR/ GENERATOR 50 KW
WIND TURBINE
GRID
17280W
8640W
4320W
2160W
1080W
540W
270W
DUMP LOAD
ANAMOMETER
DUMP LOAD BASE FREQUENCY REGULATJR
THREE-PHASE FULL WAVE RECTIFIER AND FILTERS FOR MONITORING SIX TIME THE GRID FREQUENCY
CRYSTAL REFERENCE FREQUENCY OF 360 Hz
SATURABLE SYNCHRONOUS PHASE DETECTOR
PID ANALOG REGULATOR
ANALOG TO DIGITAL CONVERTER (7 BITS)
"MASSCOMP" DATA ACQUISITION SYSTEM

WIND / DIESEL EXPERIMENTAL SETUP OF IREQ

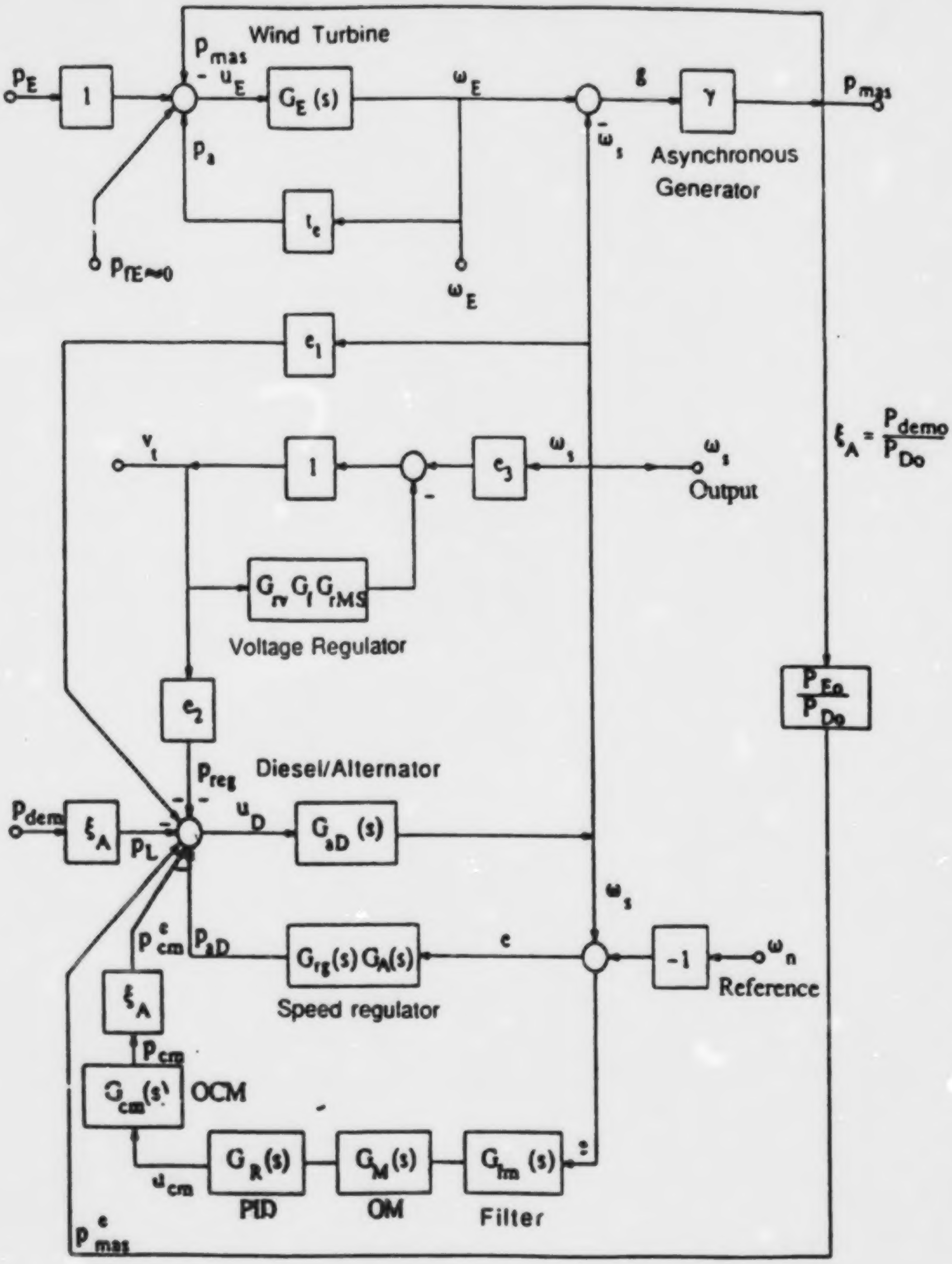

Wind Turbine
P_E
1
P_{mas}
- u_E
$G_E(s)$
ω_E
g
γ
P_{mas}
$-\omega_s$
Asynchronous Generator
P_a
t_e
$P_{fE\approx0}$
ω_E
e_1
v_t
1
e_3
ω_s
ω_s
Output
$G_{rv}G_lG_{rMS}$
Voltage Regulator
$\xi_A = \frac{P_{demo}}{P_{Do}}$
e_2
$\frac{P_{Eo}}{P_{Do}}$
P_{reg}
Diesel/Alternator
P_{dem}
ξ_A
P_L
u_D
$G_{aD}(s)$
ω_s
P^e_{cm}
P_{aD}
$G_{rg}(s)G_A(s)$
e
-1
ω_n
Reference
Speed regulator
ξ_A
P_{cm}
$G_{cm}(s)$
OCM
$G_R(s)$
$G_M(s)$
$G_{fm}(s)$
u_{cm}
PID
OM
Filter
P^e_{mas}

Figure 3 Detailed Block Diagram of a Diesel Coupled to an Aerogenerator, With Load Levelling Regulation.

Figure 4 Performance Indices of the Wind/Diesel Coupling in its Different Operating Modes, With Levelling Load Regulation

	PID Regulators				Close Loop System			
Operating Mode	$T_s^{\blacktriangle}$	$T_{ps}^{\blacktriangle}$	T_i	$T_n=T_v$	Response Time	Max. Frequency Error	Gain Margin	phase Margin
Autonomous Diesel (240kw)	260ms	6.7ms	632μs	85.9ms	0.5s	0.3%	10	39°
Diesel + Aerogenerator (50kW)	408ms	13.4ms	206ms	141ms	1s	2.5%	∞	155°
Diésel + Aerogenerator (240kw)	877ms	13.1ms	90.5ms	138ms	1.2s	2%	∞	151°
Autonomous Aerogenerator (50kw)	9.24s	10.9ms	308μs	121ms	0.2s	0.12%	1482	179°
Autonomous Aerogenerator (240kw)	52.9s	2.43ms	4.5μs	52.8ms	0.1s	.02%	1010	167°

($\blacktriangle$)T_s,T_{ps}: Time constants of the plant reduced order dynamic model

Figure 5

ELECTROMAGNETIC TRANSIENTS PROGRAM

E M T P

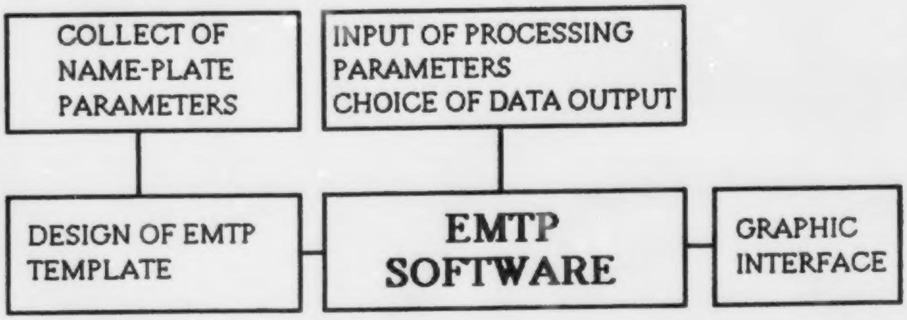
SOLVE LINEAR AND NON LINEAR DIFFERENTIAL EQUATIONS OF PREDEFINE MODELS INCLUDING:

SYNCHRONOUS MACHINE
ASYNCHRONOUS MACHINE
TRANSFORMER
TRANSMISSION LINE
LINEAR AND NON LINEAR IMPEDANCES
POWER SWITCH, DIODE, SCR
DIGITALLY-SIMULATED ANALOG COMPUTER (TACS)
AND MUCH MORE ...

RESOLUTION METHOD:

SECOND-ORDER TRAPEZOIDAL-RULE INTEGRATION

SIMULATION PROCESS



COLLECT OF NAME-PLATE PARAMETERS

INPUT OF PROCESSING PARAMETERS
CHOICE OF DATA OUTPUT

DESIGN OF EMTP TEMPLATE

EMTP SOFTWARE

GRAPHIC INTERFACE

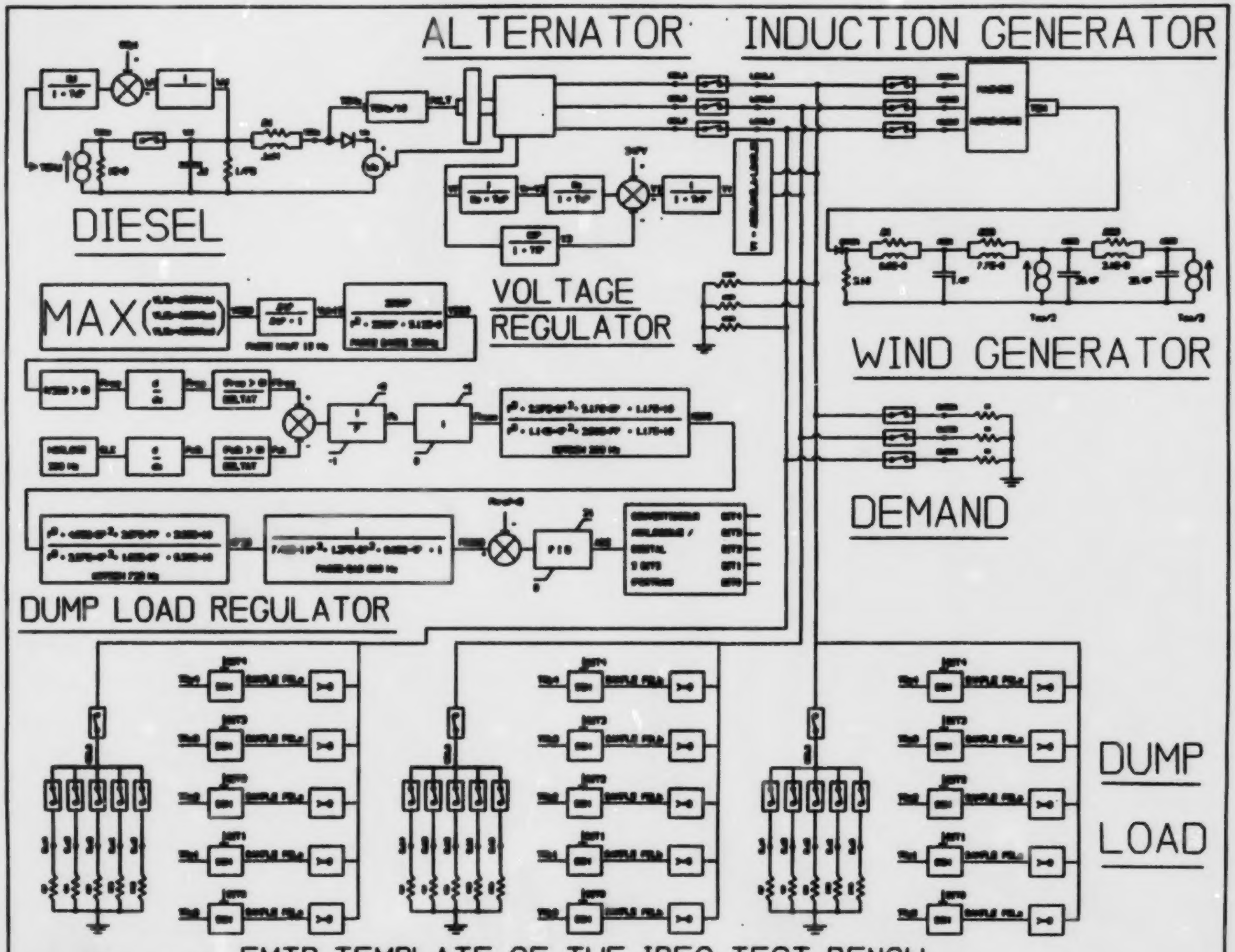
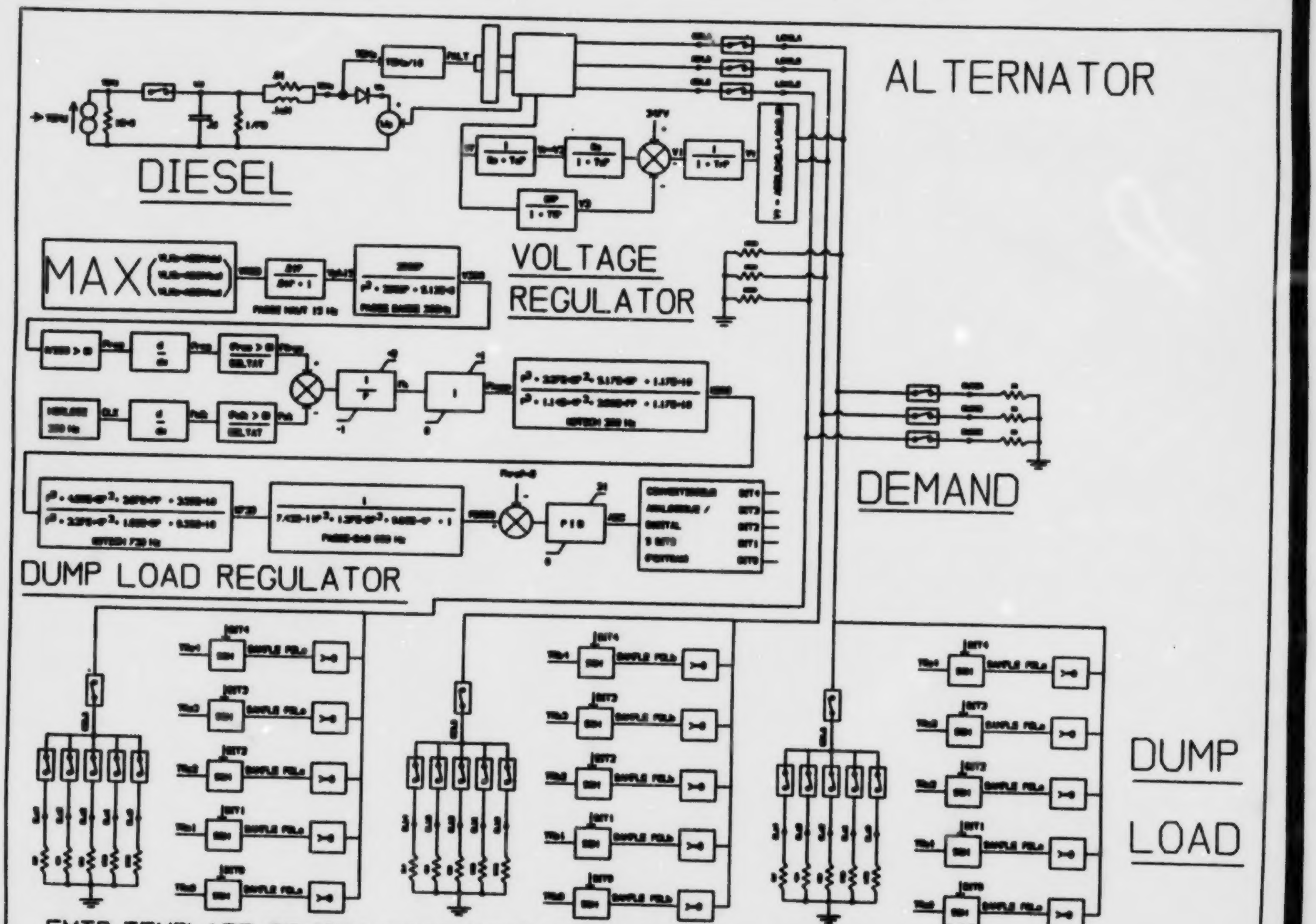

ALTERNATOR
INDUCTION GENERATOR
DIESEL
MAX
VOLTAGE REGULATOR
WIND GENERATOR
DEMAND
DUMP LOAD REGULATOR
DUMP LOAD

Figure 6 EMTP TEMPLATE OF THE IREQ TEST BENCH


ALTERNATOR
DIESEL
VOLTAGE
REGULATOR
MAX(
DEMAND
DUMP LOAD REGULATOR
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DUMP
LOAD

Figure 7 EMTP TEMPLATE OF IREQ TEST BENCH WHEN DIESEL UNIT IS REGULATED BY DUMP LOAD

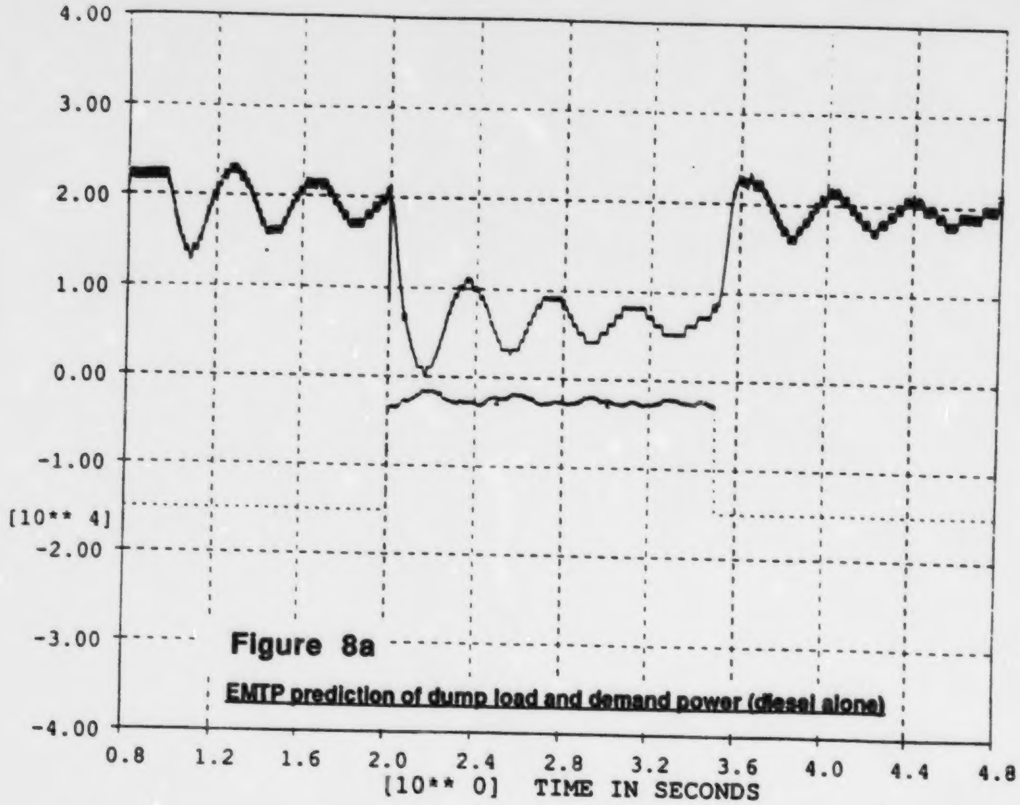


Figure 8a

EMTP prediction of dump load and demand power (diesel alone)

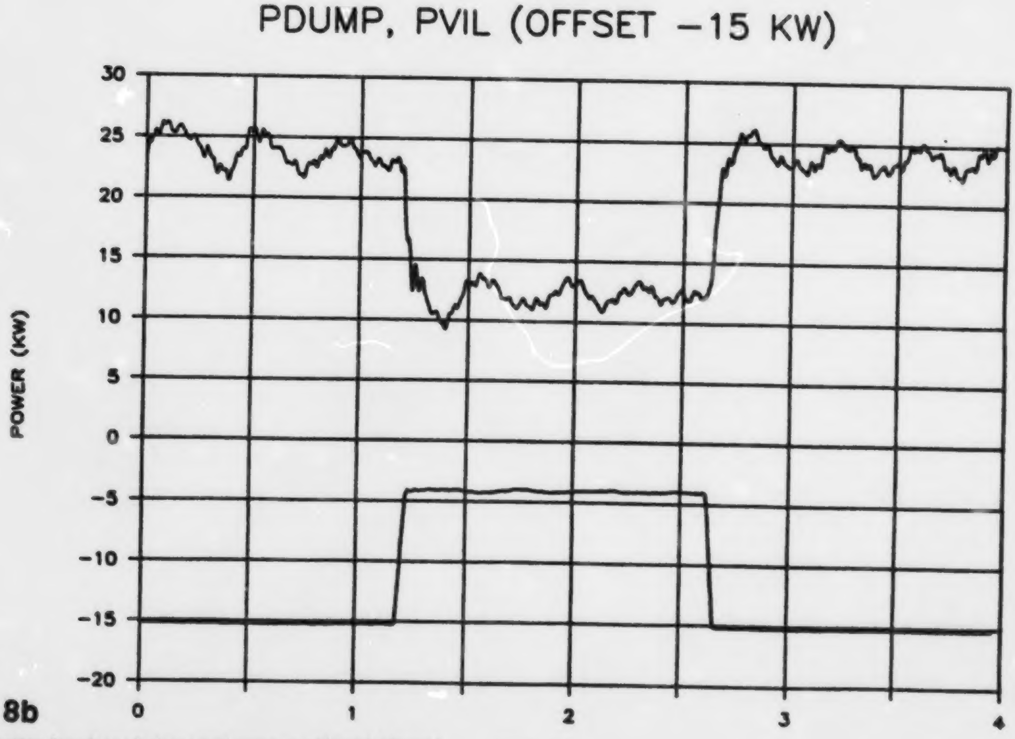


Figure 8b

Real dump load and demand power (diesel alone)

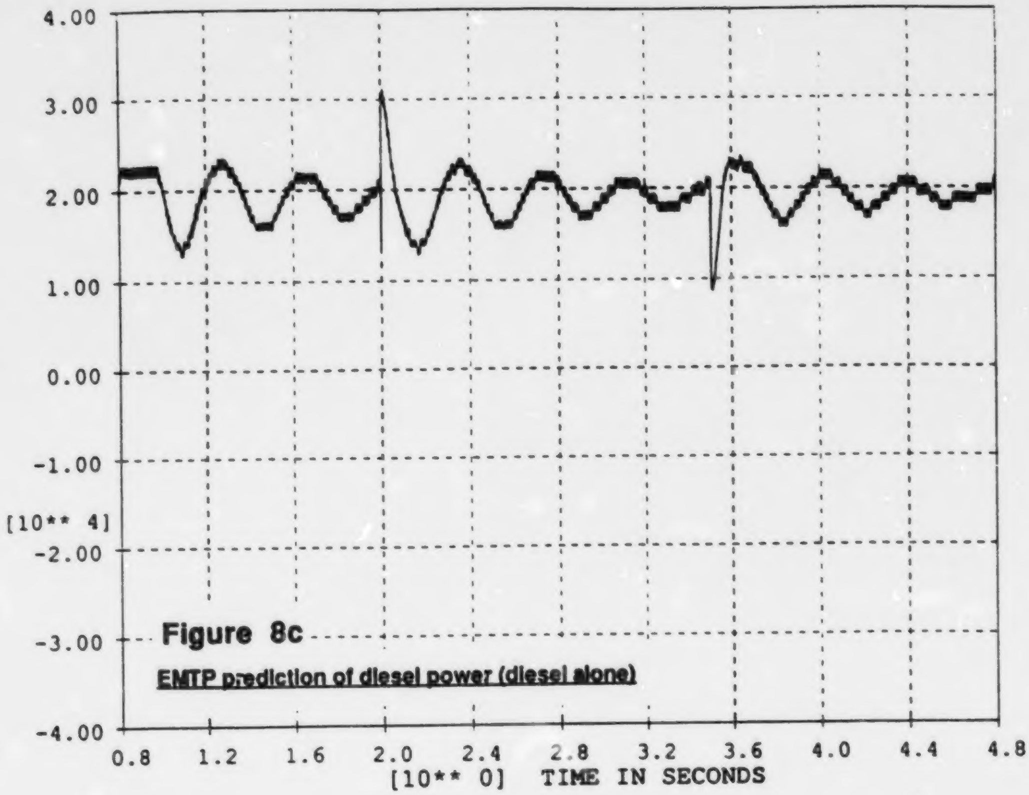
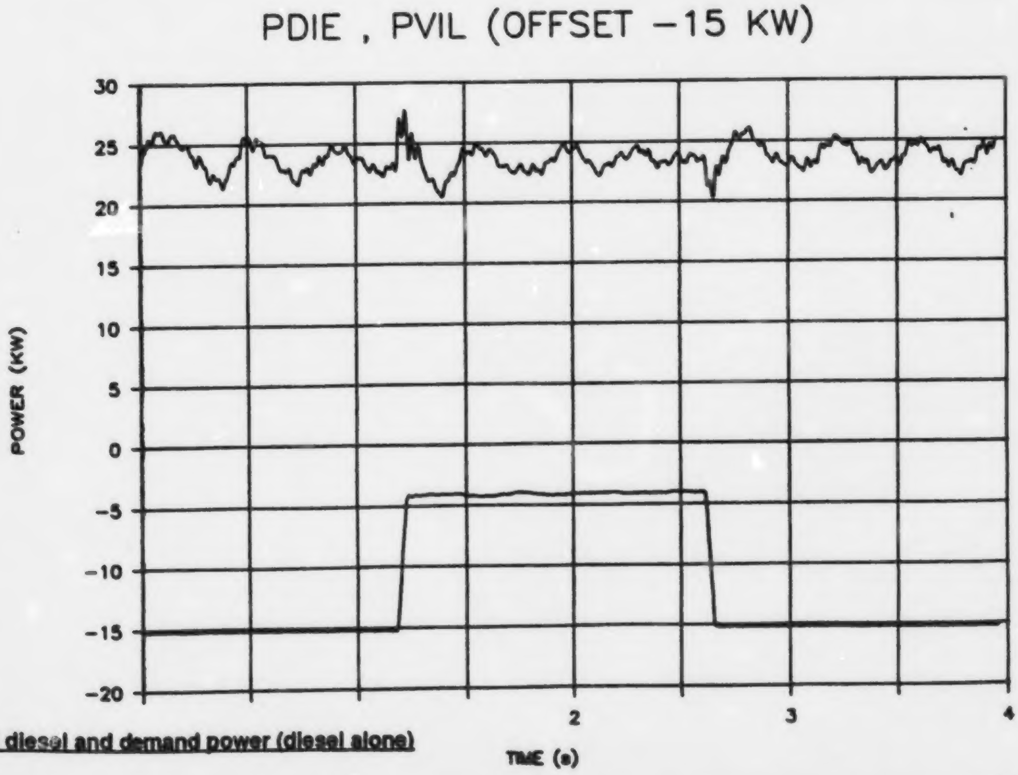


Figure 8c

EMTP prediction of diesel power (diesel alone)



Real diesel and demand power (diesel alone)

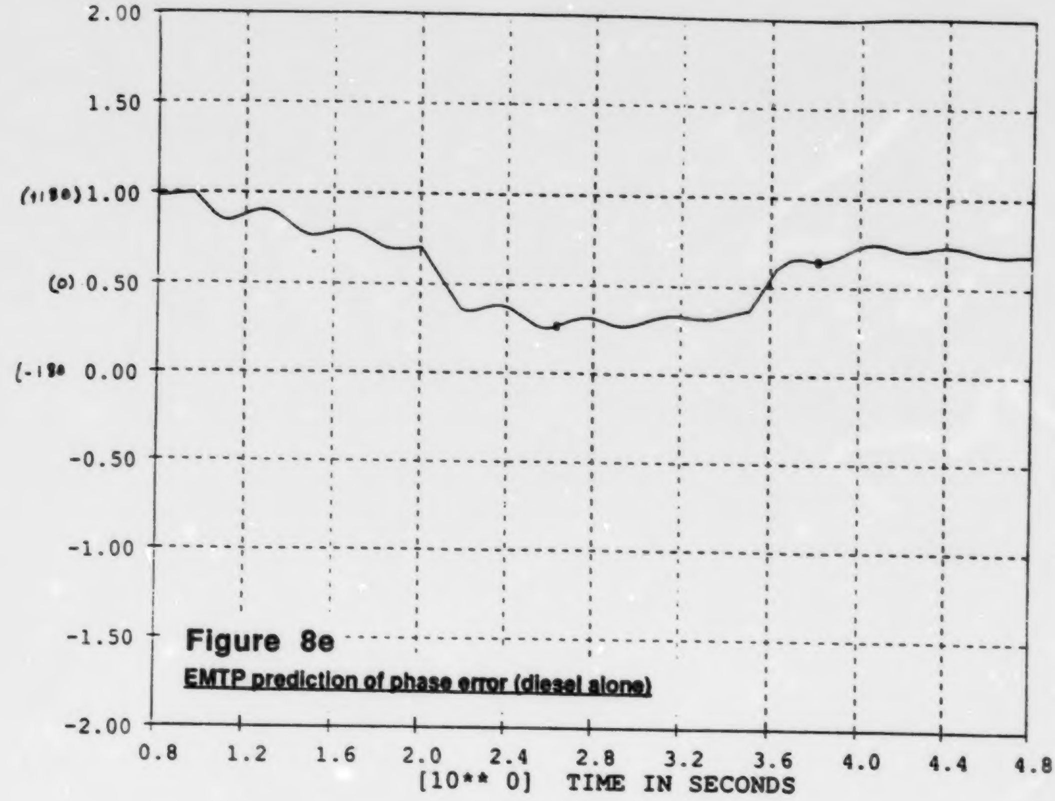


Figure 8e

EMTP prediction of phase error (diesel alone)

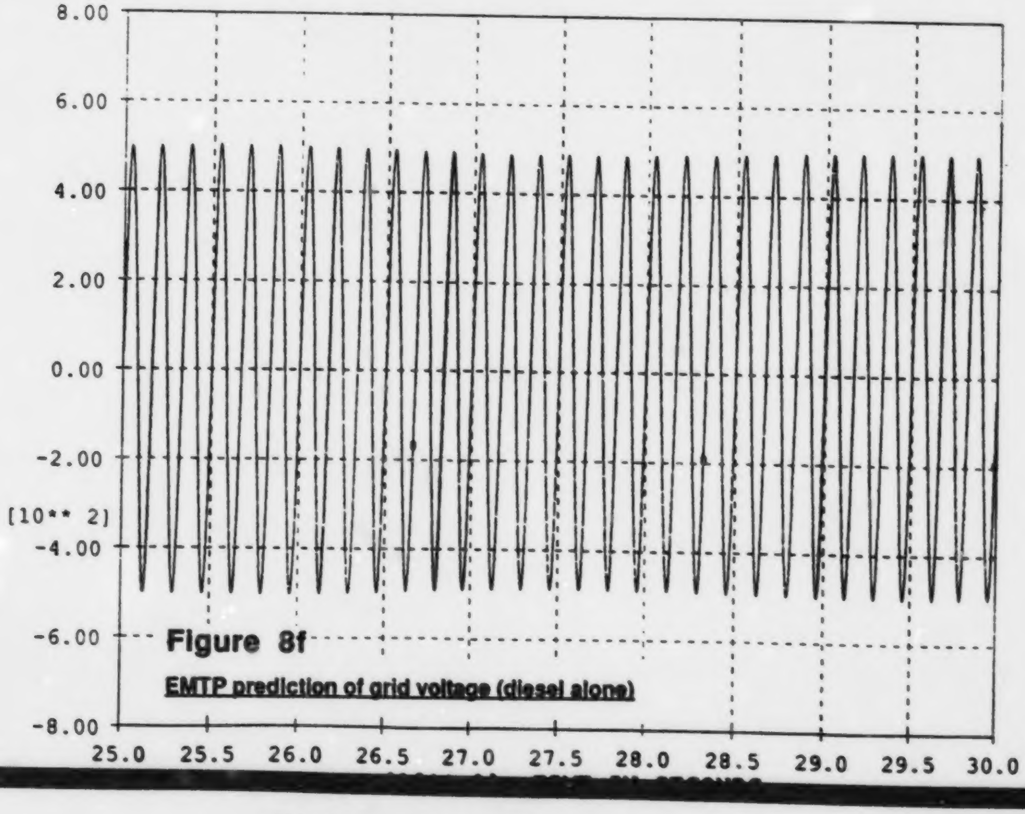


Figure 8f

EMTP prediction of grid voltage (diesel alone)

CANWEA 91

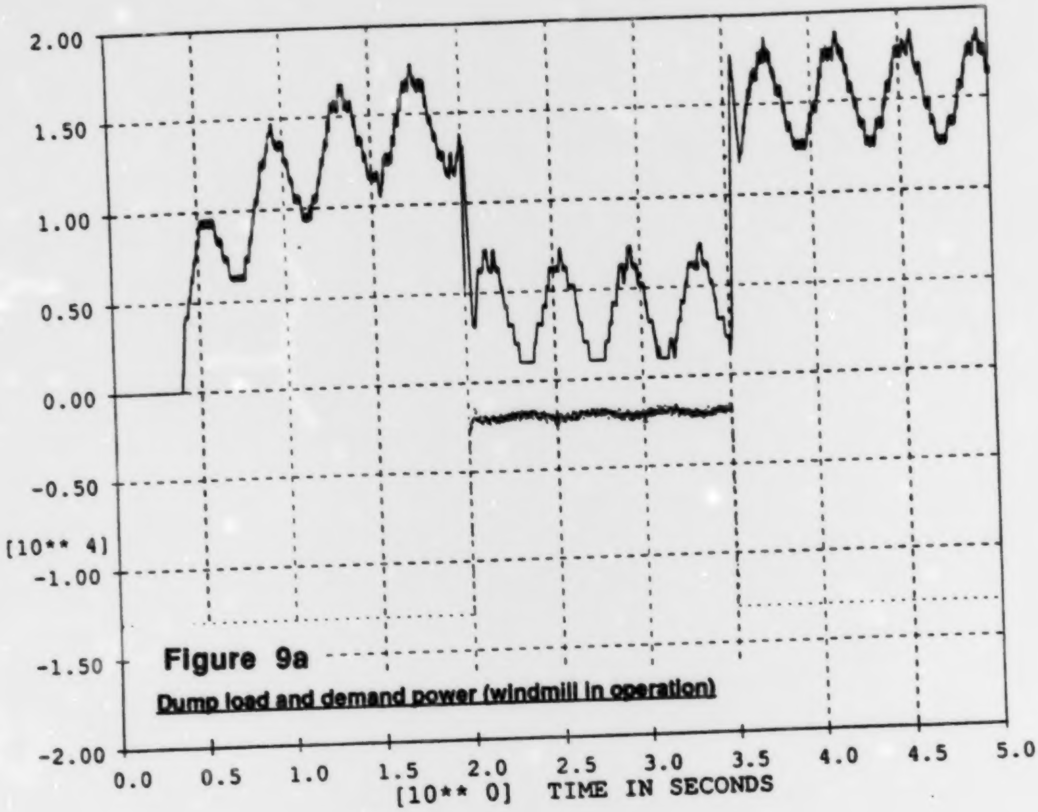
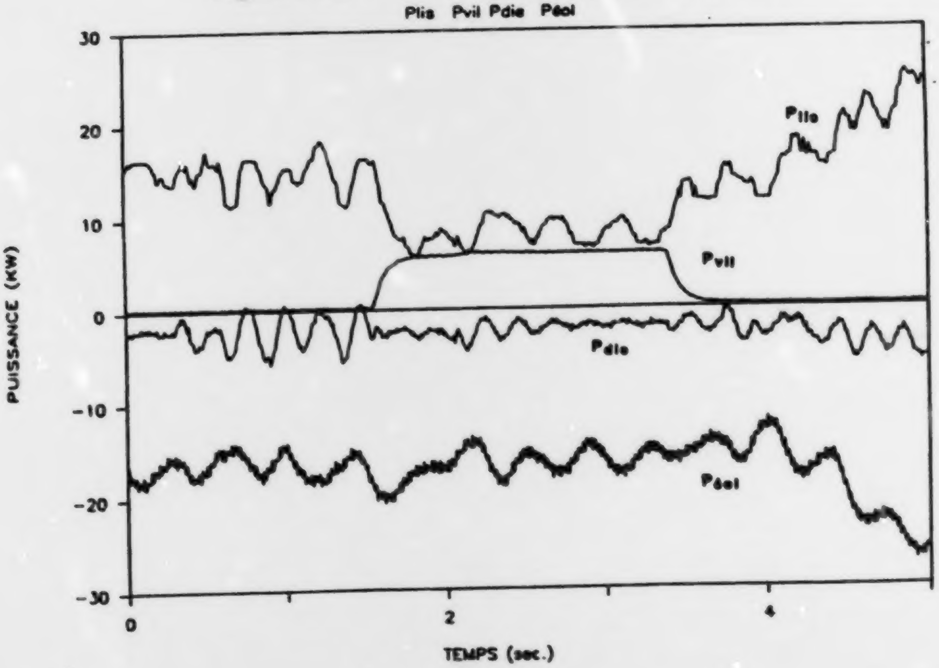


Figure 9a

Dump load and demand power (windmill in operation)

Figure 9b ENREGISTREMENT # 87



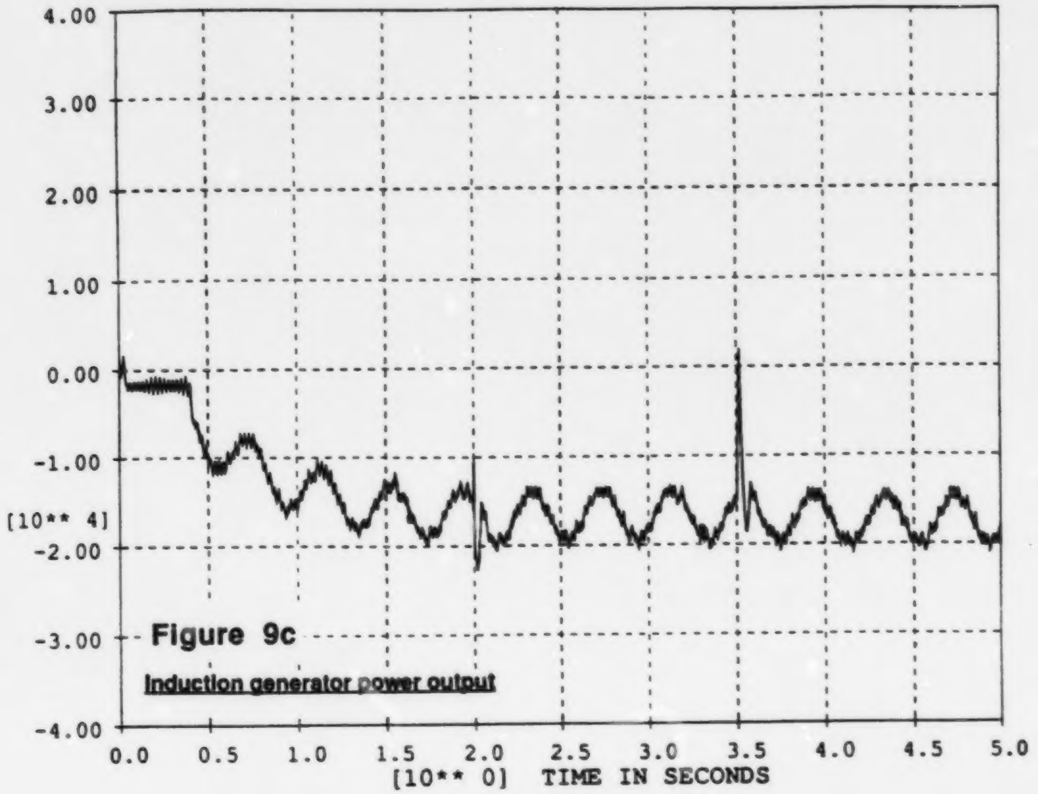


Figure 9c

Induction generator power output

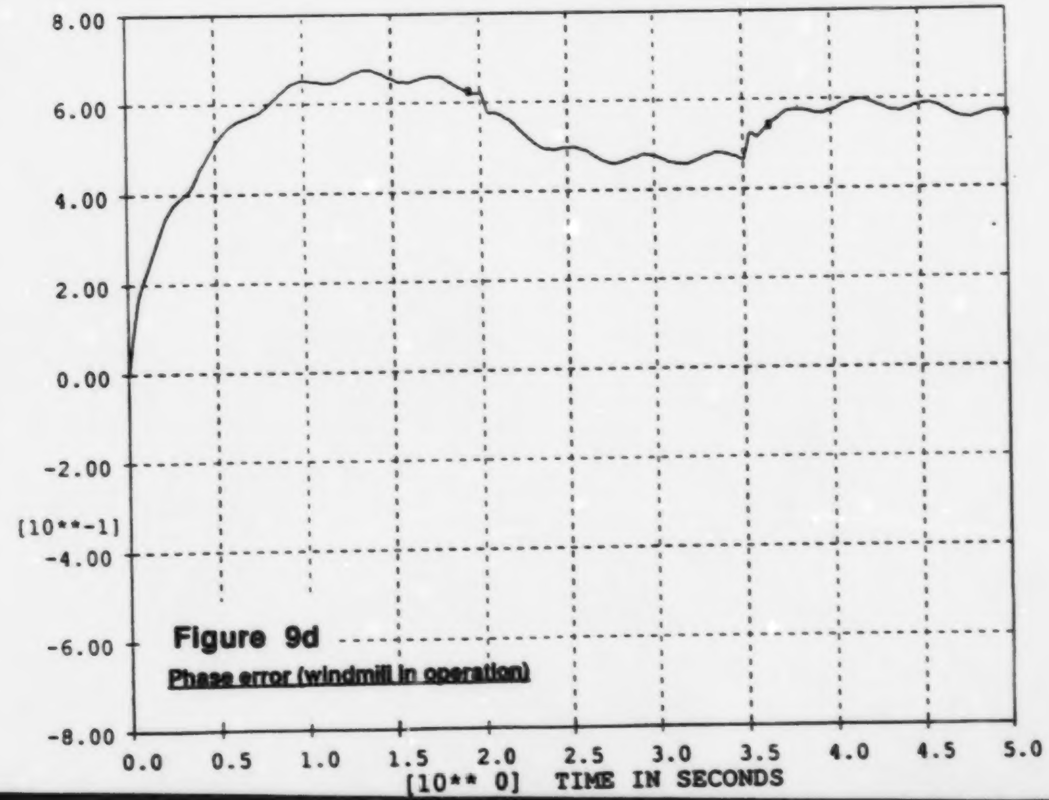


Figure 9d

Phase error (windmill in operation)

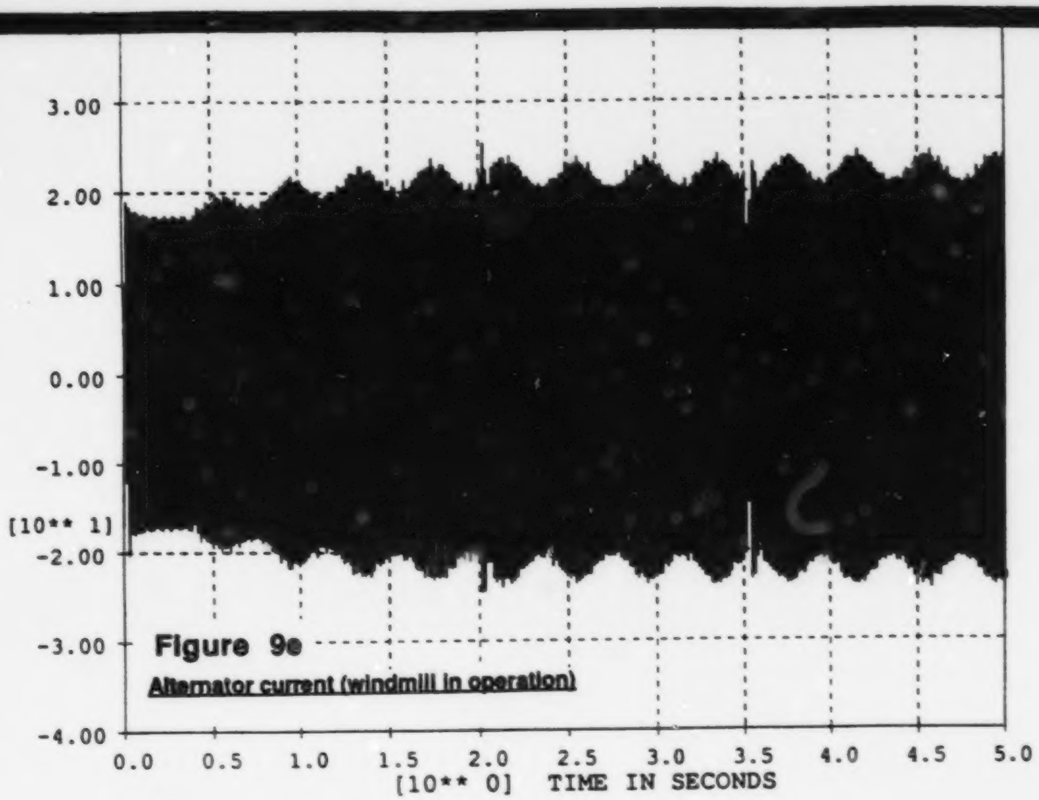


Figure 9e

Alternator current (windmill in operation)

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NAMES : gGEN_A,LOAD_A,1

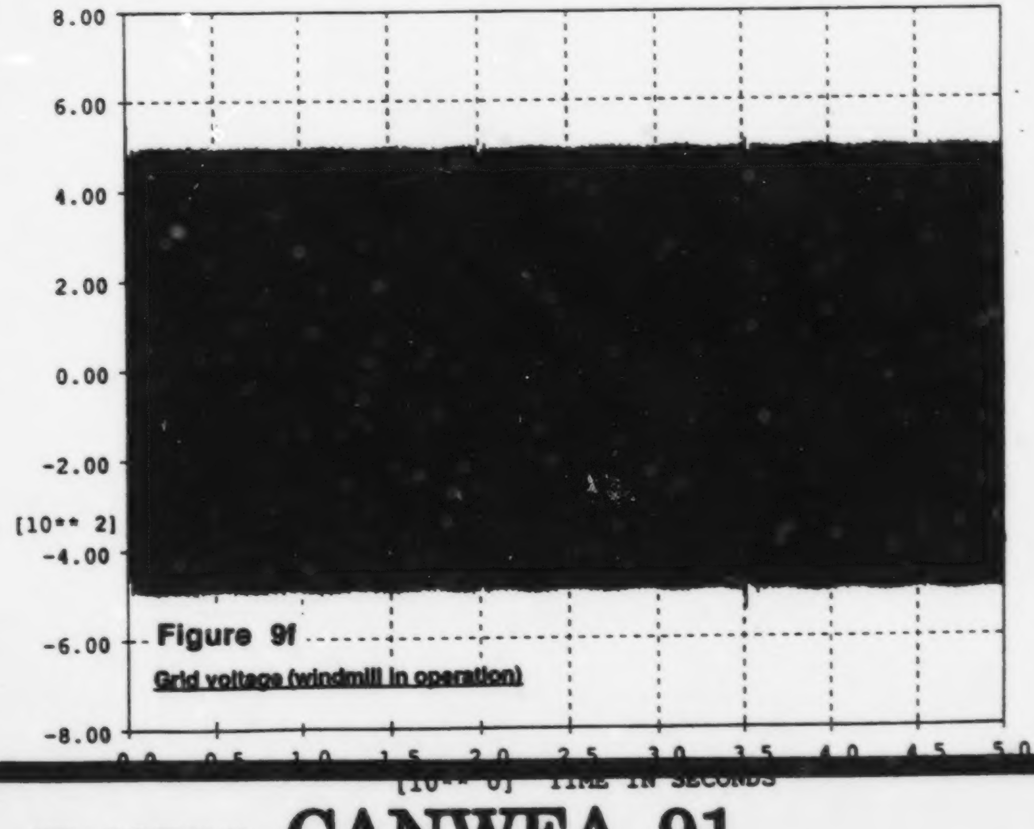

Figure 9f

Grid voltage (windmill in operation)

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NAMES : gGEN_A,1

PROCEEDINGS CANWEA 1991

RECENT DEVELOPMENTS IN WIND/DIESEL RESEARCH AT THE UNIVERSITY OF MASSACHUSETTS

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ABSTRACT

This paper gives a summary of recent wind/diesel research and development carried out at the University of Massachusetts. Under support from the U.S. Department of Energy and the Solar Energy Research Institute, this work on wind/diesel systems has been underway for over four years and is presently continuing into a second phase of work. In addition to a summary of the past four year's achievements, the paper presents a review of current work in wind/diesel system modeling, and the experimental work carried out at the University.

INTRODUCTION/ BACKGROUND

The DOE Federal Wind Energy Program is working to assist industry and utilities in achieving multi-regional U. S. market penetration of wind systems and establishing the U. S. as the world leader in development and use of advanced wind turbine technology. Under the Advanced Components and Systems research part of the DOE Federal Wind Energy Program, the overall objective of the SERI Wind/Diesel program is to improve the understanding of the control characteristics and component behavior of wind/diesel systems to assist industry in design these systems to meet the application needs of the world energy market. Specific objectives of this program are:

1) Model development and validation--validated models for evaluation of the performance and economics of competing system architectures with existing diesel electric systems.
2) Component evaluation--assessment of the performance of the key components in the wind/diesel system.
3) Advanced configuration studies--evaluation of promising new system architectures.

Under the original four year DOE/SERI contract, the objective was for the University of Massachusetts to provide a major input to the United States's wind/diesel research program. Specifically, this activity was to be concentrated on research tasks including a comprehensive wind/diesel installations survey, operational wind/diesel data acquisition, wind/diesel systems model development and validation, and wind/diesel system architecture studies. The ultimate goal of this work was the development of a systems architecture design procedure for wind/diesel systems.

The work on the wind/diesel project carried out at the University of Massachusetts has been specifically directed towards accomplishing these three broad objectives. This work is divided into the following general areas:

1) Data collection from existing national/international wind diesel projects
2) Construction of a versatile wind/diesel hardware simulator
3) Analytical modeling and software development of analytical design tools for wind/diesel systems.

Under this work, a number of scientific/technical issues have been addressed. A summary of the most important ones and their significance are shown in Table 1:

SCIENTIFIC/TECHNICAL ISSUE	SIGNIFICANCE
1. Detailed review of experience with different architectures of wind/diesel systems	Source of information for potential users and wind/diesel system researchers and developers
2. Collection of actual wind/diesel system information and required operational data	Needed as input for design studies and analytical modeling work.
3. Lack of accurate and user friendly performance prediction computer codes for wind/diesel systems	Information from these types of models needed to evaluate potential performance and economic advantages of wind/diesel systems
4. Incomplete understanding of the nature of high frequency wind turbine power fluctuations	Magnitude and duration of power fluctuations affect choice of architectures, control strategies, storage requirements, and diesel generator operation and fuel use.
5. Characterization of electrical storage options	The effective use of a wind turbine in a hybrid system may involve storage. Proper characterization of the storage component is necessary to ensure that it is properly utilized.
6. Diesel generator response to fluctuating power loads/sources	Fuel use, engine lifetime, air quality may be affected due to operational changes with the addition of a wind turbine to diesel based electrical system.
7. Development of specialized controls	The control system has a direct impact fuel use and robust operation of hybrid systems.

Table 1 Scientific/technical Issues Addressed by UMass Work

OVERVIEW OF UMASS RESEARCH PROGRAM

To address the seven technical issues previously noted, the following experimental and theoretical approaches were used:

1. In order to progress as rapidly as possible every effort was made to obtain information on wind/diesel or related projects in the U.S. and elsewhere. This involved review of the literature, attending workshops and conferences, and preparation of an extensive bibliography and review papers for our own use as well as for the wind energy community at large.

2. Operational data from both actual and potential wind/diesel systems has been obtained and studied. In some cases (Block Island) data was taken from tapes previously prepared by NASA/DOE. In other cases a variety of appropriate data collection, reduction, and analysis techniques were used. A specially designed Wind/Diesel System Simulator (WDSS) was constructed to obtain additional experimental data.

3. Computer model development was based on the application of simulation techniques specifically developed at the University of Massachusetts, beginning with a thorough examination of the key parameters being studied and the type of results required. For the quasi-steady models, codes were developed in house. For dynamic models, mathematical software packages were applied. In all cases, code development was enhanced by the simultaneous application of graphical display packages, and the input of experimental data from the WDSS for initial validation.

4. Wind turbine power fluctuations were studied by first examining the input: turbulent wind. Wind speed data, fluctuating both spatially and temporally, was examined directly and was also transformed to the rotating coordinating system corresponding to a horizontal axis wind turbine rotor. The nature of power fluctuations was elucidated with the help of data from the DOE MOD-0 wind turbines at Block Island, RI and Clayton, NM and the SERI Combined Experiment. Analysis was carried out in both the time and frequency domains. Aerodynamics codes were adapted to make the connection between fluctuating wind and fluctuating power. Tests to measure fluctuating power on a multiple wind turbine installation (Princeton, MA) have been carried out and are now under analysis.

5. Storage characterization was undertaken first by reviewing the available relevant literature, particularly battery studies performed under DOE auspices (e.g at the Battery Energy Storage Test Facility and Sandia National Laboratory). Adaptation of the results of those studies to the conditions of wind/diesel systems was undertaken with the help of computer modelling. A new lead acid battery storage model (KiBaM) has been developed at UMass. A series of tests were performed with the battery bank on the WDSS and compared to the predictions.

6. Diesel engines were studied by first examining the available literature. Fluctuating power data was also collected and analyzed from a variety of sites, including Block Island and the WDSS. An in depth study of the load fluctuations in the 10 Hz range is being undertaken on Cuttyhunk Island, MA

7. Controls directly applicable to wind/diesel systems are not readily available commercially. Therefore, a number of systems and control strategies have been designed, built and tested in house. The process to do this included the construction of a complete wind diesel system simulator (WDSS) referred to earlier. Significant advances in control included a power electronic (transistor) dump load for rapidly dissipating excess power and an overall system controller. The latter measures a variety of system parameters nearly continuously and selects the appropriate operating strategy. This WDSS, which includes a lead acid battery bank to buffer power fluctuations, may operate with or without the wind turbine and with or without the diesel.

The following sections of this paper will give a summary of the most recent technical accomplishments of this program.

SUMMARY OF MAJOR RECENT ACCOMPLISHMENTS

The following five major accomplishments of the work at the University of Massachusetts, summarized in Table 2, demonstrate the wide scope of the current program, and the significance to the U.S. wind/diesel program.

During the past year, a significant amount of work has been carried out on the following topics:

1) Analysis of Power Fluctuations from a Single Wind Turbine
2) Development of an Improved Battery Model for Time Series Simulations
3) Extension of Quasisteady Time Series Performance Models to Stochastic Time Series Model
4) Investigation of Advanced Options for Diesel Engine Operation and Control

A summary review of each of these topics follows:

ACCOMPLISHMENT	PRODUCT	SIGNIFICANCE
State-of-art review of wind/diesel systems	Technical Report, 7 Technical Papers, IEA and AWEA Design Manuals	Source of Information for potential users and manufacturers of wind/diesel systems
Data collection and analysis from actual U.S. and international wind/diesel installations	Technical Report(Block Island), 4 Technical Papers	Source of input data for analytical modeling studies, Establishment of minimum storage size for wind/diesel systems.
Construction of wind/diesel system simulator	Operating wind/diesel simulator, Technical Report, 4 Technical Papers	Unique and versatile tool for wind/diesel experiments, most useful for W/D component development and analytical model validation
Development of specialized components for wind/diesel systems (dump load, battery storage)	Experimental components and documented design procedures, 2 Technical papers	Direct development of state-of-the-art components for W/D systems
Analytical modeling and software development of analytical design tools for wind/diesel systems.	Computer Software for Performance and economics analysis, 3 Technical Reports, 7 Technical Papers	Establishment of important design tool for use by investigators and developers of W/D systems. Used to illustrate potential W/D systems (eg.-Alaska)

Table 2 Major Recent Accomplishments of UMass Wind/Diesel Program

1) Analysis of Power Fluctuations from a Single Wind Turbine

An important concern in the design of wind/diesel systems is the short term fluctuation of power from the wind turbine. These power fluctuations are due primarily to short term variations in wind speed. In addition, the interaction of a turbulent flow field with the wind turbine rotor, tower shadow, wind shear, off-axis winds, and rotor imbalances will cause cyclic surges in torque, and therefore power, at certain harmonics of the rotor speed. Power fluctuations are important for a wind/diesel system because they have a direct bearing on the control strategy and potential sizing of components, especially in systems without energy storage. Following our initial work on this subject (Manwell, Jeffries, and McGowan, 1991), this new work (Manwell, et al., 1991) describes the most recent results of an examination of the short term power fluctuations from a horizontal axis wind turbine. The intent is to more clearly define the effect of these fluctuations when a wind turbine is integrated into a multiple diesel electrical grid with no storage.

The initial research on this subject looked at: 1) effect of overloads and frequency fluctuations on the University of Massachusetts' wind/diesel system simulator's diesel generator, 2) the nature of short term wind turbine power fluctuations as measured on the SERI Combined Experiment wind turbine, 3) analytical modelling techniques for predicting such power fluctuations.

In order to determine the effect of overloading and dynamic power fluctuations from an operational wind/ diesel system, a number of tests on the University of Massachusetts diesel component of its simulator (Stein, et al, 1990) were carried out. These tests were designed to examine the degree of overload the diesel can withstand before the engine is stalled and grid support fails. Figure 1 shows the sudden application of both the dump and grid loads to present a step load to the diesel. This raises its delivered power from 9 kW to 27 kW, or 60% to 180% of rated. The grid frequency (and thus diesel rotational speed) drops to slightly above 51 Hz. The load was then removed rather than pull the diesel to a halt.

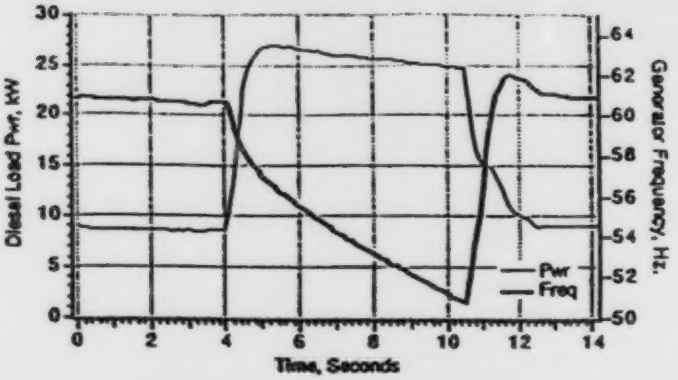

Figure 1. Diesel Transient Overload Test

In other similar tests, a smaller load, approximately 26 kw, but still substantially above the 15 kW generator rating, is supported, and it appears that the engine would not be stalled, but there could be a problem of generator overheating if the overloading were sustained.

As part of this investigation, a selected set of data taken at SERI during Phase I of the Combined Experiment (Musial, et al., 1990) was examined. The set of data included eight wind speed measurements from the Vertical Plane Array (VPA), generator power, low speed shaft torque, azimuth angle (of the rotor), and angle of attack at the 80% radius point of one blade.

A modified Grumman Windstream 33 wind turbine with a nominal rating of 15 kW served as the test machine. It has a three-bladed downwind rotor mounted on a rigid hub at a height of 18.5 meters. The original blades were replaced by ones made by Composite Engineering with constant chord, zero twist, and the SERI S809 airfoil. Before each run the mechanical pitch control was manually adjusted and fixed.

A dynamic model of a grid connected wind turbine was implemented with the software package Advanced Continuous Simulation Language (ACSL). The model consists of three parts: the first samples the wind speeds that the blades "see," the second calculates the aerodynamic torque input to the mechanical part of the model, and the last integrates torque to determine the angular velocity of the turbine. The three parts are interconnected by a single state variable (angular velocity). The model uses an eight point description of the wind field entering the rotor as input and calculates the power output and rotational speed.

The eight wind speeds that enter the model are assumed to be measurements of the wind field in a circle 80% of the diameter of the turbine. From the angular velocity of the low speed shaft the positions of the three blades are determined. For each blade the closest two wind field measurements are interpolated; the result is "rotationally sampled" wind speed. The current version of the model imposes a zero-order hold on these wind speeds. Given the three rotationally sampled wind speeds and the angular velocity of the low speed shaft, the aerodynamic part of the model finds the local tip speed ratio for five sections of each blade. For each of the five sections a separate $C_p - \lambda_r$ relationship determines the local C_p. The total power, and thus torque, is the sum of the local power contributions. At the heart of the aerodynamic section are the C_p-λ_r curves. These are found by using a momentum theory model that solves for C_L.

The simplified mechanical model includes inertias of the rotor and asynchronous generator, a power/slip relation for the generator, and a generator and gearbox loss term. Shafts are infinitely stiff, and the grid is assumed to have a constant frequency of 60 Hz. The generator is modeled as producing a rated output of 20 kW at 2% slip with a constant loss plus a loss proportional to the power output. The constants were determined from the data; with these constants the generator and gearbox together achieve an efficiency of 82% at the rated output. Subtracting the generator reaction and loss torques from the aerodynamic torque input and dividing by the combined rotor and generator inertias gives the shaft angular acceleration.

From the analysis of the data, it is first apparent that the power fluctuations follow the wind speed fluctuations closely, as is illustrated in the time series of Figure 2. The power spectral density plot of the power data (Figure 3) shows the presence of a peak at the blade passage frequency, 3P, as expected. In addition, a substantial 1P peak can be seen. This is presumably due either to a rotor imbalance or one of the blades having a different pitch from the others. It is of note that when the data is averaged over one rotation of the machine (eliminating the 1P and 3P effects), the histogram range is narrowed slightly, as would also be expected. That the decrease is only on the order of 5% indicates that the contribution of the 1P and higher harmonics are second order effects.

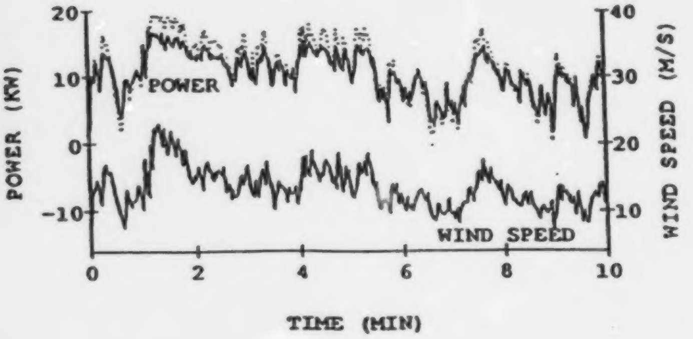

Figure 2 Power and Wind Time Series

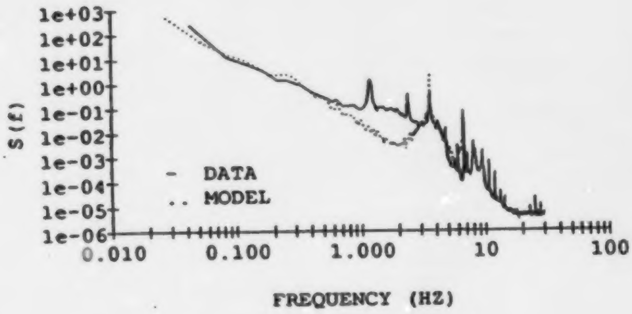

Figure 3 Power Spectral Density

The results of applying the model to the wind speed data to predict power are summarized in Table 3. As can be seen, the model predicts a somewhat higher average power than the data. From the time series plots, it is apparent that the power predictions compare favorably with the model, although again there is room for improvement. The psd from the model's power prediction shows the 3P peak, but, as expected, has no peak at 1P. For comparison, a static version of the model was also used to calculate torque and power. In this case the results were similar to that of the complete dynamic model.

	Mean	s.d.	Min.	Max	Variability
Data	10.2	3.39	-0.02	18.95	.332
Static Model	11.02	4.43	-0.08	19.19	.402
Dynamic Model	11.05	4.51	0.07	19.96	.408

Table 3: Summary of Power (kW) Data

In general, based on the tests undertaken in the first part of this study, it has been shown that the maximum overload that our diesel generator may withstand is on the order of 80% of the rated capacity for a few seconds. Any overload greater or longer would be unacceptable. Cyclic overloads with a period of 1 sec and peaks up to 20% overload have no apparent adverse effect on the grid quality. Further tests are still needed to quantify any long term negative effects on the engine or generator due to repeated brief overloads. Similar tests should also be run on other types of diesel generators to see if the results are similar.

Analysis of the SERI Combined Experiment data confirms that there can be wide power fluctuations over a short time interval. It is also apparent that the variability of the power may be greater than that of the wind speed. The use of a dynamic/aerodynamic model to predict wind turbine power fluctuations has been fairly successful. In general, there are still many uncertainties involved in predicting wind turbine power fluctuations. These uncertainties appear to be of greater impact on the results than are power fluctuations due, for example, to blade rotation. The model results give power variability and distributions that are quite plausible, although there is still room for improvement. Further study is still required to determine the typical ranges of power fluctuations which could be reasonably expected from analytical methods.

The diesel tests give an upper bound on the overload which can be tolerated, while the SERI data indicates extensive wind power dips over a 10 minute period (in this case from a mean of 2/3 of rated power to zero.) Given the wind characteristics these can be plausibly estimated. While these results are based on a somewhat atypical wind machine, they do suggest that for a single wind machine it may not be possible to count on any "gust free power" even when the mean power level is a substantial percentage of the rated output. That could mean that the decision as to which diesels can be shut off in a multiple diesel wind/diesel system should take into account only a relatively small fraction of the mean wind power available. Improving the situation could require either the use of multiple wind turbines or short term storage. Current work at UMass is considering both of these options.

2) Development of an Improved Battery Model for Time Series Simulations

Successful design and modeling of a wind/diesel system using battery storage requires an understanding of the operation of the battery. Initially, to accomplish this task, a detailed lead/acid battery model following the approach of previous battery models (Hyman, et al., 1986 and Facinelli 1983) was developed at the University of Massachusetts (Manwell and McGowan, 1991a). The original battery model was based on the battery terminal voltage and its changes under charge, discharge, and recovery. Use of this battery model typically requires extensive measurements of voltage and current for the determination of an extensive set of constants (on the order of 10).

In order to eliminate some of the problems for such cases, a new battery model has been recently developed (Manwell and McGowan, 1991b). The new model was developed specifically for use in quasi steady time series simulations of power producing systems which incorporate battery storage. For this model, it is desirable to assume that many of the variables, including the power from the battery, are constant over each time step. In these cases the primary concern is in describing power flows rather than voltage characteristics. It is also desirable to be able to take advantage to the manufacturers' data for batteries to the maximum degree possible in determining the parameters of the model. The new model, as summarized below, accounts for: 1) Decrease in capacity with increasing charge or discharge rates, 2) Recovery in charge, 3) Increase of voltage with charging current and state of charge, and 4) Decrease in voltage with discharging current and state of charge.

This model assumes that the battery is represented by a voltage source in series with a resistance. The internal resistance, R_0, is assumed to be constant and the internal voltage, E, varies with state of charge. The terminal voltage, V, is given by: $V = E - IR_0$. In addition, a current regulator is assumed to be placed between the battery and the load. This is done to ensure that the power draw, and hence current, is constant over the time step. The voltage source is modelled as two tanks separated by a conductance. One tank holds charge which is immediately available to be used by the load. The other tank holds charge which is chemically bound. The conductance corresponds to the rate constant of a chemical reaction/diffusion process (assumed first order rate) by which the bound charge becomes available. The rate at which bound charge becomes available is proportional to the difference in "head" of the two tanks. Because a chemical kinetics process is used as its basis, the model is referred to as the Kinetic Battery Model (KiBaM).

Figure 4 illustrates the KiBaM model. Each tank has unit depth, but different widths, corresponding to different volumes. The width of Tank 1 ("available") is c and that of Tank 2 ("bound") is 1-c. The combined width of the two tanks is thus equal to 1, and gives a combined tank area of unity. The combined volume of the tanks is q_{max}. Since the area is unity, when both tanks are full the "head", h_{max} is also equal to q_{max}. The valve between the two tanks has a fixed conductance, k'. The current regulator operates such that the current, I, is constant during the time step of interest.

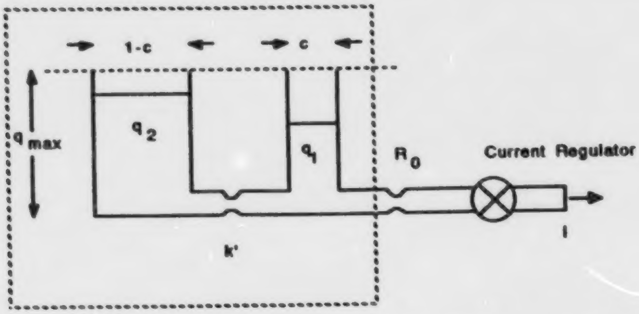

Figure 4 Kinetic Battery Model

The equations describing the model are the following:

$$\frac{dq_1}{dt} = - I - k' (h_1 - h_2)$$

$$\frac{dq_2}{dt} = k' (h_1 - h_2)$$

where q_1 = available charge, and q_2 = the bound charge

The "head" in each tank is given by the volume divided by the area. Therefore,

$$h_1 = q_1/c$$
$$h_2 = q_2/(1-c)$$

As described by Manwell and McGowan (1991b), the governing model equations can be solved using Laplace Transforms. In the simplest case, when battery voltage variation with state of charge is not of concern, only three constants are needed for the model. These are: q_{max}, the maximum capacity of the battery; c, the fraction of capacity that may hold available charge; and k, the rate constant. They can be found from battery capacity data, such as is typically provided by manufacturers.

Figure 5 illustrates the use of KiBaM by summarizes manufacturer's battery capacity vs. discharge current data for a GNX 6000C lead-acid battery (With a rated capacity of 74 Ah at the 8 hr rate). Superimposed on the data is a curve predicted by the KiBaM, whose constants were determined from the data. As can be seen the predictions closely match the data.

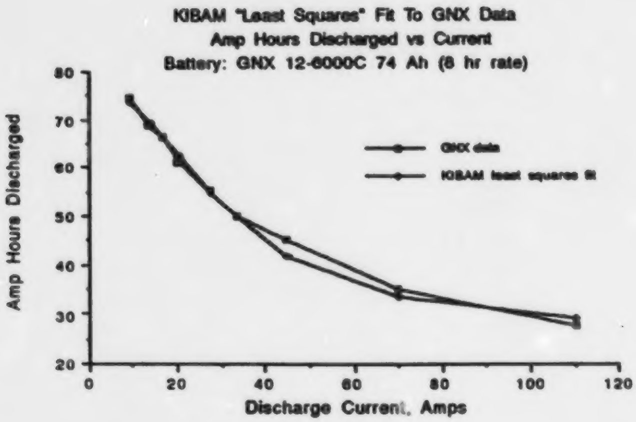

Figure 5 Battery Capacity vs. Discharge Current

The KiBaM subcomponent model explicitly assumes that charge is conserved under charging and discharge. Energy, however, is not conserved, and nominal energetic efficiencies (energy out/ energy in) must be input to the model. This reflects the higher voltages that are need in charging than are available in discharging. Also, the current version of this model does not consider temperature effects. Future work at UMass will incorporate both temperature and energetic effects into the battery model.

3) Extension of Quasisteady Time Series Performance Models to Stochastic Time Series Model

A major effort has been carried out on the long term performance simulation of wind/diesel systems. In recent work, the focus is on a combined time series and statistical approach used to model the system, select the operating strategy, and estimate the fuel use of non-identical diesel generators. The method allows the inclusion of multiple, non-identical wind turbines whose output may or may not be correlated. In addition, an improved and simplified battery storage model is integrated into the model and control strategy.

A key assumption for the main (stochastic times series) analytical model is that, within each time step, the load and wind power are assumed to be normally distributed. The net load is the mean load less the mean wind power. The variance of the net load is found from the variance of the load and the wind power. This is then used to find the maximum and minimum anticipated values. The maximum values determine the number of the diesels required to be on-line. At different times during the interval the load may be less than the minimum allowable. In this case excess power may be dumped or diverted to storage when possible. At other times storage may be needed to prevent another diesel from being turned on. The fraction of the interval where these various modes of operation occur and the corresponding fuel use are similarly calculated with the assumption of normality. The battery storage model used is based on the use of the new UMass model previously discussed.

The model, to be described in a forthcoming paper (Manwell and McGowan, 1992) , is incorporated in a program known as HYBRID1 and includes a number of improvements over previous models used at the University of Massachusetts (see Manwell, et al., 1990) as well as other time series performance models. Specific improvements include:

1) It can be applied to storage or no storage case

2) It applies to one or more diesels
3) It considers correlation between wind turbines in multiple wind turbine array system
4) It uses a flexible battery model
5) It allows for two very different control strategies

The model is designed for time steps of 10 minutes to 1 hour. Conceptually, the program has three main parts. The first is the determination of the mean net load and its probable range, in particular its maximum. The second is the storage module. The third is the diesel dispatching strategy, which then determines the fuel use, diesel starts and related outputs. Other parts of the program deal with reading of data files and preparing outputs. The most important parts of the program's model include:

1) Determination of mean and maximum of net load

The net load on the diesels (load minus wind power) is of primary importance. This is what the diesel (in some cases together with storage) must supply in order to support the grid. The key aspects of the net load are its mean and its maximum value. In order to estimate these one must consider both the wind power and the load itself. The important parameters for both of these are the mean and the variance.

For the current version of this model: 1) the wind speed, wind power, and load are all assumed to be normally distributed over the time step, 2) the variability of the wind power from a single machine is estimated from that of the wind speed 4) the variability of multiple machines is derived from that of a single machine by taking into account correlation limits, 5) the mean net load is the mean load less the mean wind power, and 6) the variance of the net load is equal to the variance of the wind power plus that of the load.

2) Storage Model
The previously described Kinetic Battery Model (KiBaM) is used in the overall system model

3) Diesel Dispatching Strategy

At present the model will consider up to three diesels, all of which are assumed to have a linear fuel vs. power curve assumption). The dispatching strategy falls into two categories: i) no-storage, ii) with storage. For the no-storage case the number of diesels that are on is determined by the maximum net load during the interval and the immediately previous operating history (when a minimum run time is specified). Which diesels are on is determined by their fuel efficiency. The strategy used assumes that diesels are turned on in order of their no load fuel consumption, and is described in more detail in other recent work (Manwell, et al., 1990).

For the storage case, two types of operating strategies which use storage are plausible and have been implemented in the program. They involve the use of storage in two very different ways, specifically:
(A) Least Storage Operating Strategy
The Least Storage Operating Strategy seeks to use energy from storage to assure that the number of diesels that are on is determined solely by the average net load rather than the maximum load during the interval. It does this by checking to see if there is enough storage to to supply the difference. When it is impossible to have on only the diesel needed to supply the mean load, the algorithm continues to seek the lowest number of diesels that will suffice.
(B) Most Storage Operating Strategy
This control option is similar to the Least Storage Operating Strategy in that it uses storage to select the diesel operating strategy. In this case, however, it seeks to use storage to the maximum extent. It does this by shutting off as many diesels as possible, subject to the availability of stored energy. This is essentially a multidiesel version of the "cycle-charge" (McGowan, Manwell, and Connors, 1988) approach.

Initial runs for this new wind/diesel performance model have been based on the actual operation of the Block Island wind/diesel system as reported by Manwell, McGowan, and Jeffries (1989). Specifically, HYBRID1 modeled operation of the Block Island, RI, wind/diesel system for 23 hours from 5 p.m. on February 23,1982 to 4 P.M. February 24,1982. The no storage system included diesel #8 (225 kW), diesel #9 (400 kW) and the 150 kW MOD-0A wind turbine (Jeffries, 1991). During the test period diesel #8 power production was held constant at about 110 kW. Diesel #9 power output varied from about 90 to 280 kW. Figure 6 (Jeffries, 1991) shows actual load and power production data from the diesels and the wind using one minute averages.

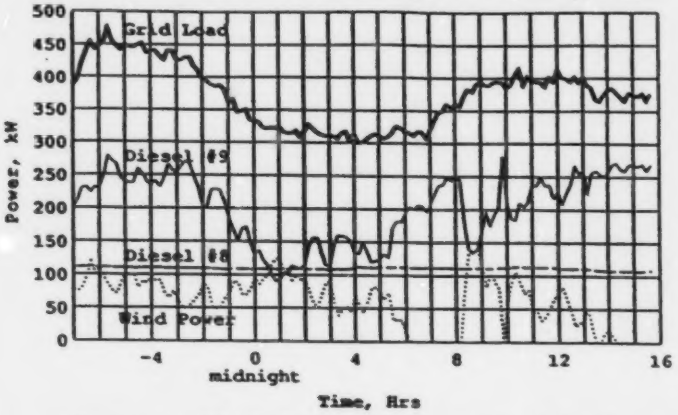

Figure 6 Block Island Experimental Data

Figure 7 shows the load and HYBRID 1 model results (using 10 minute time steps) for the power production of the the two diesels and the wind turbine for the same 23 hour period (0 hours is midnight). The results match test results very well. Actual fuel consumption of diesel #9 for the 23 hours was 4939 gallons. HYBRID1 predicts 4942 gallons. As shown, results from HYBRID1 closely reflect actual test data shown previously in Figure 6.

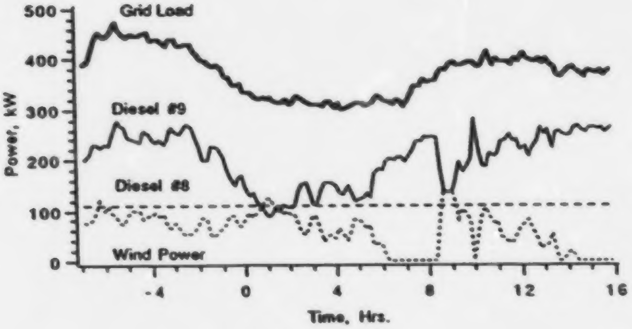

Figure 7 Model Results- Block Island Simulation

Based on the results of the initial model development, and the first validation runs using this computer model, it has been shown that the new model combining time series and statistical methods, has proven to be a powerful tool. Current work on the refinement and the improvement of this model is underway.

4) Investigation of Advanced Options for Diesel Engine Operation and Control

Due to advancements in power electronics, and subsequently static inverter technology, the concept of operating diesel generator sets asynchronously, and conditioning the variable voltage/variable frequency power with a static inverter, to provide 60 Hz power, could be both feasible and economic. A proposed system architecture, as shown in Figure 8, is currently under investigation.

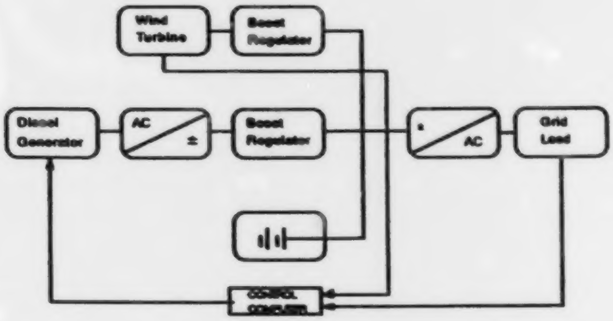

Figure 8 Schematic of Variable Speed Diesel Generator Hybrid System

From preliminary diesel generator tests, as shown in Figure 9, a series of fuel consumption curves have been produced and are applied to the Wind/Diesel models developed at the University of Massachusetts. Comparisons to constant speed operation are presented, showing the potential for fuel savings.

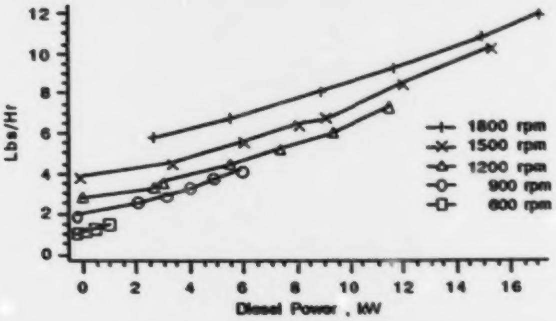

Figure 9 Variable Speed Diesel Fuel Consumption

Other benefits, such as reduced engine start/stop cycling and diesel wear must also be considered as well as economic comparisons for fixed and variable speed system architectures. Current work at UMass is addressing these problems

CONCLUSIONS

As can be seen by the previous discussion, research at the University of Massachusetts has addressed problems that are of paramount importance in helping to make wind/diesel electrical systems realistic alternatives for stand alone applications and non-interconnected electrical power systems. In addition, it is our opinion that the current work will have increasing relevance to interconnected grid, high penetration wind systems applications as progressively more wind turbines are added. In such cases issues such as short term power fluctuations, load/resource correlations, storage, load management, application of power electronic convertors, power quality enhancement, specialized controls, and economic issues such as capacity as well as fuel savings value, all become increasingly important. Experience gained in the wind/diesel area should result in much more rapid solutions to these problems.

ACKNOWLEDGEMENT

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AN OVERVIEW OF DANISH WIND-DIESEL ACTIVITIES AS PER NOVEMBER 1991

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Abstract

The paper outlines the wind-diesel activities in Denmark with emphasis on the work done at Risø National Laboratory. A summary of the background is given in terms of the publicly funded wind-diesel work previously done at Risø. Then follows an outline of the present wind-diesel activities at Risø and a summary of commercially related work in Denmark by industry and one NGO. Finally the application of Danish wind-diesel technology through development agencies is outlined.

1. INTRODUCTION

The wind-diesel activities in Denmark comprises mainly three areas of activities. The paper outlines all of them with main emphasis on the work done at Risø.

One area is the systems development and R&D work done in the framework of publicly funded Danish institutions. The majority of this work has been done at Risø as part of the Danish Government Energy R&D Programme (EFP), and recently work has been initiated at teh Danish Centre for Renewable Energy, the "Folkecenter". Another area of work is the systems development work done by Danish telecommunication companies and by Danish industry resulting in, presently, three to four groups of companies developing stand-alone and othe hybrid wind energy systems for commercial sale. The third is wind-diesel systems application in third world countries financed by the Danish International Development Agency, either directly or through UNDP and by the European Community EC. Risø acted as consultants and, occationally, project managers in such projects.

2. BACKGROUND

The Wind-Diesel Project at Risø National Laboratory was initiated in 1983 as a part of a cooperative effort, funded by the Nordic Council of Ministers. The partners in the original project were The Test Station for Wind Turbines, Risø National Laboratory, Denmark, and The Department for Electrical Machines and Power Electronics, Chalmers University of Technology, Sweden. On the basis of this joint project Risø National Laboratory subsequently initiated other wind-diesel activities in the form of projects, funded by a number of grants from the danish Energy Research Programme EFP.

The purpose of these activities was to support the development of wind-diesel systems into commercially available systems, and the main intentions and goals of the activities were outlined and presented in 1984, ref. 1., where two different consistent wind-diesel system design philosophies were outlined: One was an advanced, complex concept with energy storage, aimed at a maximum fuel saving. The other was a practical, simple concept without energy storage, aimed at a maximum reliability and adequate fuel savings.

The advanced system concept was developed by Chalmers, ref. 2., and it has been tested at Risø, ref. 3. The simple system concept was developed into an experimental system at Risø, ref. 4. At the same time a wind-diesel test facility was established at Risø, ref. 5, and development of dynamic and logistic simulation models was initiated, refs. 6 and 7. The main outcome of this is outlined below:

A wind-diesel test facility with a modular switchboard, a consumer load simulator, a wind turbine and a data acquisition system. The test facility was described in ref. 5 together with a proposed outline for a standard wind-diesel test and evaluation procedure, which also included logistic and dynamic computer simulation of the tested system.

Computer models for structural and mechanical dynamic system design analysis. The models were used for design of Risø's experimental system, in particular the clutch-and-flywheel modification of the diesel generator necessary for the design of the system and for prediction of the dynamic characteristics of the system, ref. 14.

Risø's 55/30 kW experimental wind-diesel system. The system concept has been argued and described in a number of papers and ref. 4 summarizes the outcome of the work with the system, including its impact on commercial systems. A test report on the system has been issued, ref. 8, and the system has recently been used in the investigation of possibilities of improving the performance of the basic class 1 concept by the so called diesel 'backdrive technique', ref. 15. and it will be used for verification of dynamic electrical models in the JOULE project "European Wind-Diesel Software Package" in which Risø participates, ref. 16.

The WDILOG modular logistic simulation model ref. 11. The model predicts the energy flows, fuel consumption and fuel savings for a prospective wind-diesel system. The model is able to represent all four system classes of ref. 4 applying a 'standard' control system logic which is easy to modify. The model has been used to evaluate Chalmers system, ref. 3, and it has also been used in a larger concept study on wind-diesel systems for China, ref. 7.

Field testing of the Chalmers wind-diesel system at Risø, ref. 3. The system had already been laboratory tested at Chalmers using a simulated wind turbine generator, but the actual field testing proved to imply more problems than anticipated in particular concerning interfacing and control of the wind turbine. Chalmers participated in the dynamic testing of the system and continued the development of the variable speed control scheme for the wind turbine, ref. 2.

Thus the outcome of the activities at Risø is a) a versatile test facility, b) two wind-diesel systems at each end of the spectrum of configurations, and c) computer models for logistic and dynamic mechanical modelling. The trends in current wind-diesel development are covered by projects in that the two systems represent the very simple system concept believed to be a presently economically optimal configuration, and the very sophisticated concept believed to be a future optimal configuration. The work is summarized in ref. 17.

3. RISØ WIND-DIESEL ACTIVITIES

Most of the wind-diesel work done under government R&D grants have been carried out at Risø. The aim has not been to develop an actual system design for direct commercial marketing, as this would be in conflict with Risø's neutral standing. The aim of the work has been to establish the necessary understanding and knowledge and make it available to Danish authorities and industry. Part of this has been to investigate feasible system concepts and to test and demonstrate their applicability. The following outline of Risø's activities should be seen in this perspective.

3.1 Risø's Experimental wind-diesel System

The experimental system was designed and built at Risø 1984-85 as part of the facility for theoretical and experimental work, and it includes features that were new and to some extent controversial at the time. The experimental system is a simple, consistent concept with a) a 55 kW Standard Bonus Induction Generator wind turbine, b) a 30 kW Bukh diesel genset with clutch/flywheel conversion and a mechanical proportional governor, c) a dump load regulated proportionaly to the frequency deviation of the local grid. The system is self-regulating in that the system is regulated by the component controllers, and the control scheme is:

The frequency is regulated by the diesel governor (positive torque) or by the dump load controller (negative torque) depending on whether the wind power surplus is positive or negative.

The voltage is always regulated by the compound voltage regulator of the diesel genset's synchronous generator is running whether the diesel is stopped or not. The voltage varies roughly proportionally with the grid frequency.

Only very simple supervisory controls are needed to handle diesel start/stop engine and clutch operation. Until recently this has been done manually as the essential objective was to demonstrate the system's self-regulating ability. Recently a simple control system has been developed for the system and implemented on a PC in connection with industry grade circuitry. It was developed in cooperation with the Technical University of Denmark and implemented as part of an M. Sc. project.

3.2 Wind-Diesel Test Facility and Testing

The wind-diesel test facility at Risø is described in detail in ref. 5. It consists of a local soft grid with a programmable load bank and a power switch board with modules for each component of a wind-diesel system. The load bank can simulate active and reactive load patterns, and the modular layout of the switch board makes it possible to combine components into wind-diesel systems as needed. Fast reacting sensors are built into the switch board and connected to a PC based data acquisition system.

The 60 data channels available include electric currents, voltages and power (active and reactive), i.e. power quality and power flows for each component in addition to special data channels such as wind speed and direction, shaft torques and speeds, and fuel consumption rate. The test facility is capable of both long term statistical and short term dynamic measurements, refs. 3 and 8, and tests performed include testing of the frequency regulation of Risø's experimental system with controller settings allowing the diesel set to absorb part of the excess power, ref 15.

The test facility is intended for use in connection with both model verification and system performance documentation. Therefore, as part of the work with the test facility, procedures for standard test of wind-diesel systems including the assessment and experimental verification of system economics and power quality were proposed in ref. 5. These procedures incorporate the use of logistic and dynamic simulation models.

3.3 Logistic/Economic Modelling.

In order to assess the economics of a prospective Wind-diesel system, one will usually proceed in two steps.

The first step is to determine the fuel savings from a number of system configurations in a number of consumer demand scenarios as compared to diesel-only power generation. This is done by logistic models which simulate the system behaviour under given wind speed, consumer load demand, control strategy and component specifications. Risø has developed logistic models for 'deterministic' simulation based on time histories for wind speed and consumer load, refs. 9 and 11, and for 'statistic' simulation based on wind speed and consumer load frequency distributions, ref 10.

The second step is to determine the economics of some of the configurations in order to select the most promising system(s). Based on the added costs of the systems and the corresponding fuel savings the systems are evaluated in terms of usual economic measures such as net present value of the investment, ref 9, cost of fuel saving, refs. 7 and 9, and financial/economic internal rate of return on the added investment, ref 7. In addition to this Risø has also developed a methodology to include the effects of improved power availability in the economic assessment of wind power in power supply systems, ref 12.

Time History Logistic Models. The SIKKE-model, ref. 9, was developed for use one mainframe computers to analyse 'collective energy systems', i.e. energy systems combining a wide range of renewable energy technologies and storage techniques, intended for use with conventional energy sources in local communities in Denmark. Although the SIKKE-model includes wind turbines, diesel generators and battery storage systems, its emphasis is on larger, more diversified systems.

The WDILOG-model, ref. 11, was developed for use on PC's for dedicated analysis of single unit wind-diesel systems, although multiple unit systems may be represented in a simplified way. The model has a modular structure with the control strategy in a separate subroutine, that may be changed or replaced. The model can represent all 4 classes of systems defined in refs. 4 and 11, including systems where the diesel genset is modified with a clutch and flywheel. The model has been used and verified in connection with the testing of the Chalmers' system, ref. 3, and the implementation of wind-diesel systems in China, ref. 7. Recently a pilot version of the model has been developed with the ability to model real multiple unit wind-diesel systems.

As a time history model WDILOG has a 'memory' and is therefore able to represent the effects of features such as energy storage, delay times, minimum diesel run time etc. WDILOG is based on the commercially available program package CYPROS, ref. 13, whose simulation module SIM includes standard operations such as equation solving, data handling and graphical representations. The WDILOG model is included in the European Wind-Diesel Modelling Software Package, ref. 16., developed under EC grant within the JOULE programme.

Statistical Model. The WDSTATMOD-model, ref. 10, has been developed for use on PC's to estimate key figures relevant for the design of medium-scale wind-diesel systems. The diesel fuel savings are related to wind-diesel operation as compared to diesel only operation with the same diesel generator specifications. The calculations are based on a simplified statistical model for static operation of the wind-diesel system.

The results are intended to be used more for comparison of different systems rather than as absolute figures, and the program is designed for medium-scale systems (say 100 to 1000 kW). Since the model is statistic it has no memory, and it is therefore best suited for analysis of systems with a simple control strategy and without storage. The model works directly with wind data given as Weibull distributions and it is very fast to use, and therefore results for a large number of scenario's may quickly be estimated.

Economics. The economics of wind-diesel systems is generally evaluated on the basis of present valuing, i.e. cost analyses where the extra investments, O&M costs etc together with estimated fuel savings are used to assess the value of the extra investments as compared to diesel-only generation using the same diesels. This approach is used in refs. 7 and 9.

In contrast to this the economics of large, conventional power systems is often evaluated by cost analyses where the cost and benefit of unserved energy is included in addition to the topics listed above. This approach is chosen in the methodology developed by Risø for use in feasibility studies and project planning contracts for evaluation of local and regional power systems including wind turbines. The power availability often increases when wind power is implemented, and thus a wind-diesel system will offer better power availability than the same diesel system without wind turbines and possible storage devices. Therefore, when doing a cost-benefit analysis to obtain the net profit from implementing a wind-diesel system, one should compare the cost of the wind-diesel system with the cost of a diesel system offering the same power availability. A technique to quantify this is outlined in ref.12.

3.4 Dynamic Modelling and Control

Dynamic modelling at Risø has mainly been concentrated on system design analysis, refs. 6 and 14. Emphasis has been on finite-element type structural modelling, with simple spring-and-dashpot representation of the electrical machinery. Structural matrices were presented in ref. 14, that allows a model to represent each component at it's true speed of revolution.

A model of Risø's wind-diesel system was used to ascertain that the natural frequencies of the system do not interfere with those of the diesel engine, and crash start of the diesel was analysed. The analyses showed that no damage of the diesel engine and clutch should be expected, and that grid frequency fluctuations would be acceptable. This was verified by measurements, ref. 8, in connection with a refined frequency domain version of the FEM model.

This model cannot adequately predict the grid voltage fluctuations, and studies were therefore initiated in collaboration with the Danish Engineering Academy on dynamic modelling of Risø's wind-diesel system with emphasis on the electrical machines. These dynamic models of Risø's system are fully dynamic and have been developed in parallel with measurements on the system. So far two master theses have been completed, and current conclusions are:

The voltage regulation of the cheap, standard synchronous generator is difficult to model because of saturation effects.

Electrical machine parameter values are generally not available from the manufacturers of the electrical machines, and some of the parameter values are difficult to measure.

The studies will continue with emphasis on these topics which are also included in the dynamic model part of the the European Wind-Diesel Modelling Software Package, ref. 16., developed under EC grant within the JOULE programme. This part of the project aims to develop a modular model running in the CYPROS environment, ref. 13., permitting a wide range of system configurations to be modelled. The model is based on component models such as mechanical models (wind turbines, diesel engines), electrical models (electrical machines, power electronics) and control models (voltage and frequency controllers, standard controllers). A given wind-diesel system is then modelled by combining component models into a systems model.

A main issue is the development under main responsibility of Risø and Norwegian Electric Power Research Institute (EFI) of program routines able to assemble system model equations on the basis of component equations for the system configuration chosen by the user. A pilot version of the model is presently (Nov. 1991) running with the ability to combine one or two wind turbines, diesel engines, synchronous machines and induction machines in any desired combination on a standard grid.

4. COMMERCIAL SYSTEMS DEVELOPMENT

Development of wind-diesel systems for commercial application is done by Danish industry and by Danish Center for Renewable Energy, the "Folkecenter". The work within systems design and layout done at Risø does not aim directly at commercial systems but rather on developing the know-how necessary for the commercial application. Therefore Risø contributes to the commercial development in an advisory role and participates in the development in cooperation with industry.

4.1 Manufacturers

Commercial development is 1991 characterized by three groups or alliances in which Danish wind turbine manufacturers have joined Danish diesel engine manufacturers/contractors to develop commercially viable system concepts. The alliances seen to be strategic rather than corporate in the sense that in a specific case any wind turbine manufacturer could supply wind turbines stand-alone, add-on or in connection with any diesel manufacturer and vice versa. In addition to this the development of energy components for such systems is underway in Denmark, one example being a desalination plant. Each will be described briefly below.

Nordtank/Bukh diesel:: Nordtank has in cooperation with Neste Advanced Power Systems (NAPS) of Finland developed a stand-alone wind turbine concept called NANOSAW, ref.18. The system includes variable speed operation of the WTG through power electronics, a battery storage and an optional cycle charging diesel generator, a class 4 system according to the classification of ref. 4. The prototype system employs a 130 kW Nordtank wind turbine and a 25 kW cycle charge Bukh diesel generator set. The concept aims at applications in levels of technical infrastructure similar to the Nordic one including arctic applications, and a demonstration system is being installed in northern Finland.

Bonus/Grenaa Diesel: Grenaa Diesel is developing a simple wind-diesel system in cooperation with Bonus. The system concept will be based on that of the experimental system at Risø, ref 4, i.e. basically a class 1 system with a standard wind turbine connected directly to a diesel generator of the Grenaa Diesel 300-600 kW diesel generator range. The concept includes a the possibility of low load operation of the diesel generator as advocated in ref. 16. A demonstration system is being planned at the site of Grenaa Diesel in Jutland, and this system also incorporates the Alfa Laval Desalt VVC water desalination unit described below.

Micon/BWSC: Micon is partly owned by Burmeister & Wain Scandinavian Contractors (BWSC), a large contractor specializing in diesel powered electricity supply systems using the B&W MW range of diesel engines. This group is presently considering to build an autonomous demonstration system in connection with a Danish power plant. The system will have a number of Micon 250 kW wind turbines coupled directly to one or more B&W MW size diesel generator(s) in a low penetration multiple unit class 1 system (ref. 4). The Danish utility NESA participates actively in this system development and demonstration activity.

Alfa Laval Desalt: During recent years this company has developed a desalination unit based on the Vacuum Vapour Compression (VVC) technique, a highly optimized distillation technique. A prototype unit with 100 m^3/day capacity is operating with an energy consumption of the order 11 kWh/m^3. The concept has very promising potential for use in connection with wind-diesel systems as shown in ref. 19, a joint presentation by Risø, Alfa Laval Desalt and Danish Power Consult. A VVC unit will be incorporated in the demonstration system at Grenaa Diesel.

4.2 Danish Folkecenter for Renewable Energy

The "Folkecenter" is a non profit institute similar to an NGO, working within a broad field of renewable energy sources and concepts. It has recently initiated the development of a small class 4 system, in which a sub 10 kW wind turbine of "Folkecenter" design is connected through power electronics to a battery bank. A small diesel of a few kW is added as a cycle charger. It is the intention to develop the system into a system design which is available for commercial application in remote third world communities by manufacturers who are too small to do their own systems design. A demonstration system may be installed on a small Danish island.

The "Folkecenter" is also working on a hydrogen cycle concept, which will eventually also be applicable in the wind turbine and wind-diesel context.

5. APPLICATION THROUGH DEVELOPMENT AGENCIES

As the wind-diesel technology is still not considered a fully developed commercial technology, there are few examples on pure commercial application. Most applications are through various development agencies, and this goes for Danish systems as well. Examples on installations are given below.

DANIDA/UNDP Pilot Projects. During the years 1982-1988 the Danish International Development Agency financed a wind energy project in the Republic of Cape Verde. Initially 2x55 kW Vestas wind turbines were connected to the main diesel grid (3.5 MW) of the capital Praia, thus making a very low penetration wind-diesel system. Later on followed a 55 kW Bonus wind/60 kW diesel system with 150 Ah battery storage (a class 3 system, ref. 4) for the rural centre Assomada. As an offspring of these projects a 55 kW Vestas WTG was bought by a hotel and connected to its 100 kW diesel generator, making it a commercial class 1 system. Risø acted as engineer in these projects which are described in ref. 20.

EC Pilot Project. In 1988 a class 2 system with 3x55 kW Bonus wind turbines and 280 kW Caterpillar diesel generator was added to the existing diesel powered supply network of the Chinese Dachen Island as part of the project described in ref. 7. Risø participated in this project as consultant to EC and supplied a wind-diesel test facility in connection with the Bonus system.

DANIDA Implementation Project. Based on the experience with the pilot projects a large scale project has been formulated for the use of wind energy in Cape Verde. It can be argued whether the project is a high penetration wind farm project or a medium penetration wind-diesel project. At MW levels of wind turbine power the borderlines become gray.

The project is expected to start soon, and in the first phase moderate penetration levels of 10-20 Pct. wind energy will be reached. Eventually the wind energy penetration may reach a level of more than 45 Pct. of the entire national diesel powered electricity supply of Cape Verde, ref. 21, corresponding to approx 3.5 MW installed capacity. Risø has acted as consultant to DANIDA during the formulation of the project.

6. CONCLUSION

Wind-diesel technology is not yet considered a commercially available and fully developed technology. Publicly founded development and application work still dominates the area around the world, and work is going on in many countries. This paper has outlined a variety of activities in Denmark, showing the general picture.

There is now a number of industry groups, more or less firmly established, which are engaged in the development of wind-diesel systems in Denmark. In an effort to improve the credibility of their systems they will be demonstrated in Denmark before being deployed in far-way locations, and electric utilities participate in this development. Equally important is the large scale DANIDA implementation project in Cape Verde, which will have an important demonstration effect.

Thus, after a somewhat slow start, things in Denmark seem to move faster, more determined and with a stronger industry and utility commitment.

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EVALUATION OF WIND/DIESEL SIMULATION MODELS

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INTRODUCTION

The concept of using wind turbines to assist traditional diesel powered electrical generators in relatively small electrical grids has been under development for some time and the concept, referred to as wind-diesel, shows great promise for economic application. Substantial amounts of diesel fuel can be saved if wind energy is utilized to reduce the energy requirements of the diesel engine.

A number of wind-diesel configurations have been proposed and are under study. These systems range from the simple, with a single wind turbine operating in parallel with an existing diesel generator set, to the more complex, using multiple wind turbines with power ratings exceeding the rated capacity of the grid, operating with storage systems, autonomously from the diesel generator set. The more complex systems require more intricate control algorithms and control systems to maintain system stability throughout the operational range.

To adequately assess the economic potential of wind-diesel applications a number of separate parameters must be considered; wind speed distribution, load distribution, fuel costs, diesel engine characteristics and operating strategy, etc. Evaluation of these parameters are best done by the use of computer simulation models that accurately project system performance over a period of time. To be accurate these models must be based on a thorough understanding of each of the individual parameters and the correlation over time between the parameters.

In Canada efforts to develop wind-diesel simulation models were initiated by NRC with the development of their GASTOPS model. However GASTOPS, a dynamic simulation model developed on an analog computer, proved to be so complex to operate that it has seen little practical application.

EMR initiated development of a logistical simulation model several years ago when they contracted with Buchan, Lawton & Parent (BLP), an Ottawa consulting group to develop a wind-diesel model. This model has been modified several times and is presently in a usable form.

In the past several years, both Ontario Hydro and Hydro-Quebec have started work on wind-diesel models. Hydro-Quebec completed an economic model to evaluate the potential of their high penetration no storage concept several years ago [21], and are presently developing models to perform detailed economic analysis and technical evaluations of wind-diesel scenarios. Ontario Hydro has recently completed a model for the Canadian Electrical Association that uses a Lotus 1-2-3 based model to assess the technical and economic effects of various renewable energy technologies in remote systems.

Internationally, many organizations have been involved in the development of wind-diesel models.

A dynamic simulation model and a long term logistic model for the analysis of wind-diesel control strategies, system performance and economic was developed by by Uhlen and Skarstein [1][2] in Norway. Hour-by-hour simulations, by Desrochers [3], were used to show the percentage of wind penetration and the efficiency of a hybrid system. A model, University of Massachusetts Long Term Model, (UMLTM), developed by Rogers et al [4], is capable of simulating a system consisting of a wind turbine, diesel, battery set complete with rectifier and inverter and dumpload. This model has been modified by Leotta [5] to include photovoltaic simulation. In the United Kingdom dynamic and transient modelling of wind/diesel systems was undertaken with the development of a detailed numerical time series model for assessment of system stability and power quality by Tsitsovits [6]. Logistic models were also developed in the UK. A flexible time step model, developed at RAL/Imperial College [7] ran with 2-second wind data and a constant load data to overcome limitations caused by one-minute step models [8].

Although many models have been created and some experimental demonstrations completed, little systematic validation for existing models using field applications has been done. This report describes efforts to validate several existing wind-diesel simulation programs using the wind-diesel test bed at the Atlantic Wind Test Site.

In the validation work, four simulation models were evaluated. The models selected are not meant to be representative of the best programs available. The selection of the models was based solely on the availability of different models to the evaluation program.

The programs considered included:

- The EMR Model, a logistic wind/diesel simulation program that simulates hourly data of one second values, originally developed for EMR by BLP and modified subsequently by Keller [9].

- Ontario Hydro's model, a long term technical and economic analysis model, developed by Wilf Moll for the Canadian Electrical Association.

- WDILOG, a logistic time series simulation model for wind/diesel system simulation of either long or short term periods, developed at Riso National Laboratory in Denmark [10].

- The IREQ MACRO Wind/Diesel model, developed with the assistance of several technical consultants, also designed to provide long term technical analysis.

The evaluation program consisted of several steps. First the available models were obtained and the logic of each program deciphered. Numerous runs were made on each of the models to obtain some feel for ease of use. General comparisons for the four wind/diesel simulation models were carried out by executing the programs using actual hourly wind and load data taken from Fort Severn over a one week period. Field tests were then performed on the wind/diesel test bed at AWTS. The control strategy utilized intermittent operation of the diesel generators, which represents a similar control strategy to most operational diesel systems.

Funding for this project was provided by the NRC-IRAP-R program and AWTS core funding.

GENERAL DESCRIPTION OF THE EXISTING MODELS

EMR Model

The EMR model is a logistic model that computes performance of a wind/diesel system, consisting of wind generators, diesel generators, energy storage systems and dump load, on a second by second basis for 24 hours. Since the system is monitored on a second by second basis, the model can provide high resolution data on the performance of the system. This is particularly attractive for the analysis of such parameters as storage requirements and system power transients. However because the model is a logistic model that computes the probabilistic occurrences of each of the independent variables and then correlates the combined effects of the variables through a number of transfer functions to produce the final output, it is necessary that each of the steps in the process be confirmed to accurately represent the computed value. To do this, the simulation software is divided into four programs, each of which can be executed independently. This allows the user flexibility in the operation of the program and also provides reference points that can be used to assess the validity of the computations.

The four programs include WNDPWR, WNDSIM, LDSIM, and WNDDSL. WNDPWR generates power curves for the wind turbines selected for the analysis, WNDSIM generates simulated one hertz wind speed data from input values of average and standard deviation. LDSIM generates one hertz data of load similar to WNDSIM.

WNDDSL is the main program that computes the second by second output of the system based on inputs describing the diesel plant and the control algorithm, and from the outputs of the other three programs. Detailed descriptions are presented in the AWTS report [12].

Ontario Hydro Model

Ontario Hydro has developed a renewable energy simulation model for the Canadian Electric Association that enables the comparison of a traditional diesel generator system with a hybrid system made up from a number of renewable energy options. Both technical and economic evaluations for hybrid systems can be carried out using this model.

The model, written in Lotus 123, allows the user to compose a stand-alone electric power system consisting of diesel generators, wind generators, photovoltaic arrays, small hydro generators and storage batteries. The user can select any arrangement of equipment he wishes and the model will compute the technical effects of such a selection and an economic analysis for comparative purposes. The model calculates performance and fuel consumption of both a diesel only system and a hybrid system using one hour increments of actual wind and community load data. The calculations are performed on four weeks of data, representing one typical week from winter, spring, summer and fall. The calculations are then prorated to provide annual values.

Within the main program MODEL.WK1, technical parameters such as small hydro power output, PV array rating, wind turbine size and RPM, diesel size and operational limits and storage battery rating are entered first. Four weeks of data are then entered representing one hour averages of parameters such as wind speed, community load, solar radiation, and hydro power for the various seasons. The model than computes the corresponding one hour averages of energy production for both the diesel only system and the hybrid system. Results for the test run are presented in a results summary.

An important capability of this model is the economic analysis of the options considered. Based on general cost estimates for installation and O&M costs, the model estimates the installed cost of each of the systems being considered, performs a discounted cash flow analysis and computes net present values and present worth cost of energy, at various discount rates, for the options considered. Detailed descriptions are presented in reference [12].

IREQ Model

IREQ has been active in the development of wind-diesel models for several years. Their first model was used to provide an economic analysis of their high penetration no storage concept of wind energy utilization [21].

The current model, presently being further modified by IREQ, generates simulated files of hourly wind, electrical load and heat load data and then combines these with preselected combinations of wind turbines and diesels to provide simulation of a complete energy system. The model operates with multiple non-identical wind turbines interfacing with multiple, non-identical diesels that can be controlled in a variety of operating strategies, to provide the electrical and heat load needs of a community. The model, developed with the assistance of several technical consultants on a Lotus 123 spreadsheet, uses a family of worksheets, each of which develop components, simulated wind, simulated electrical and heat load, etc. of the hourly data to be ultimately used in the master worksheet model.

An interface worksheet AUTO123.WK1 is the main supervisory program that links the other worksheets as requested by the user.

The wind simulation worksheet WINDCRE.WK1 creates hour by hour simulated wind regimes for a week. Seasonal averaged wind speed data and turbulence intensity is required before simulation. The methodology, adapted from J. Templin [13], is similar to the one used in the EMR model.

There are two types of load worksheets, a simplified electrical load simulation program, ELECRE.WK1 and a simplified heating load simulation program, HEATCRE.WK1. Both of them use the same function of second order Fourier Series.

In the IREQ Macro wind/diesel model, the performance worksheet uses the wind turbine worksheet, TURBINE.WK1, to retrieve up to three different types of wind turbine performance curves. The wind turbine worksheet TURBINE.WK1 contains seven existing wind turbine performance curves. Additional power curves can be input in the performance worksheet if the existing wind turbine does not match the wind turbine desired.

Battery storage in this model is based on the deep discharge battery storage model developed at the University of Massachusetts (UMASS Version 3.0) [14].

The performance worksheet integrates the individual worksheets described above to give an estimation of overall performance of a wind/diesel system. Detail descriptions were presented by Jones [15].

WDILOG Model

WDILOG, a logistic computer model, from Riso National Laboratory, Denmark, comes with powerful capabilities in data handling and graphics. Written in FORTRAN 77, this simulation program consists of a number of routines, which were developed using the commercially available simulation software CYPROS. The use of CYPROS greatly enhances the graphics capabilities of the model. Either long or short term (yearly or hourly) system simulation can be performed with the model and a wide range of simulation time increments from 0.1 minute, upwards can be selected. The program can simulate performance for the four most common types of wind-diesel systems under investigation.

There are three options for wind simulation in the main program. The first is used if no wind speed data exists for the site being analysed. Data is generated in the program simply by providing the average wind speed value. Wind speed data, for relatively short term simulation periods, may also be read directly from a sequential file. The wind speed data may also be read from a data file for longer term simulation periods of up to a year where hourly wind speed data for each month are retrieved as required.

WDILOG simulates diesel performance as a package, rather than as individual units that are controllable with their own fuel consumption characteristics. It is assumed that all diesels can operate in the negative power range, although the minimum allowable load is a user specified parameter, and that their performance curves for fuel consumption are linear and identical throughout the diesel operating range. Power loss from synchronous generators is considered. An energy storage system is optional in this simulation model. A detailed description is presented in AWTS' report [12].

REVIEW OF THE SIMULATION MODELS

EMR Model

Wind Simulation - WNDSIM

WNDSIM was validated by comparing the real second by second wind data acquired at the Atlantic Wind Test Site with the data simulated from the WNDSIM program. Hourly average wind speed and turbulence calculated from real wind samples, were input to WNDSIM to generate second by second simulated wind data. A number of hourly second by second real wind samples with average wind speed ranging from 6.8 to 15.2 m/sec with turbulence levels ranging from 7.9% to 15% were compared to simulated wind data with the same values.

Both real and simulated wind were binned to compare the distributions for each one-hour wind. Typical results are shown in figure 1. In all tests simulated winds agreed very well with real wind over a wide range of wind speed and turbulence levels.

Load Simulation - LDSIM

LDSIM was developed using an identical algorithm to WNDSIM. The average values of load and "turbulence" of load are entered and the second by second values of load are generated. Although earlier tests by Keller, on limited available data, indicated

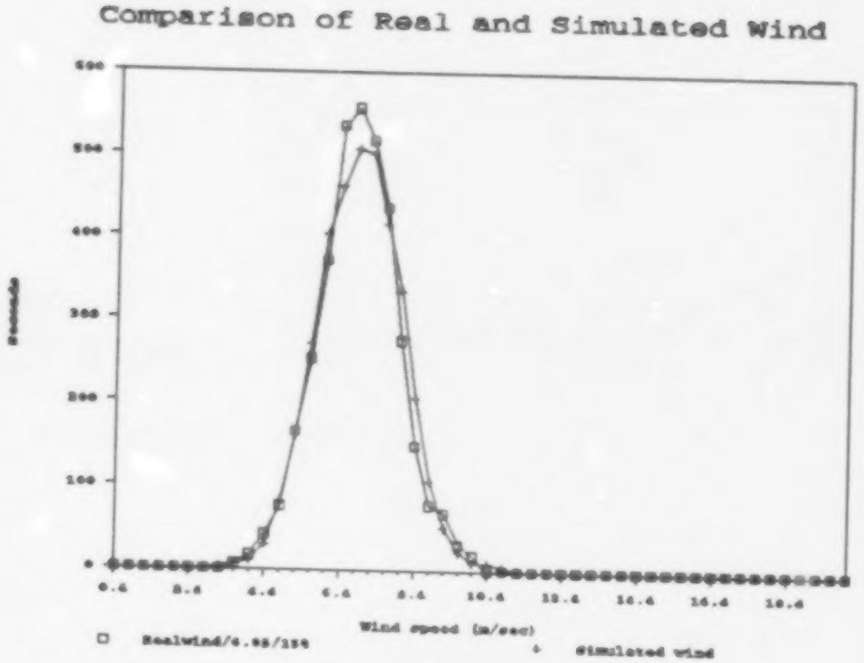

Figure 1

that the frequency distribution of the load matched the distribution in the wind data, AWTS had no detailed data available with which to compare LDSIM's simulated data.

Wind Power Simulation - WNDPWR

In WNDPWR the power curve of a wind turbine may be described by either providing a performance power curve for a specific wind turbine or providing enough information to the program to utilize the generic C_p curve in the program to generate a power curve. The first option gives good accuracy for each wind turbine but discrepancies occur if the generic C_p curve is used. Figure 2 shows results of real versus generic C_p curves for Bonus 150 wind turbine using EMR's program. The errors in energy generation using the generic curves can be substantial but the curves are useful for early analysis. The data used for the analysis was AWTS actual data. The differences in projected energy output is summarized in table 1 for the Bonus and also the Lavalin 250 wind turbine.

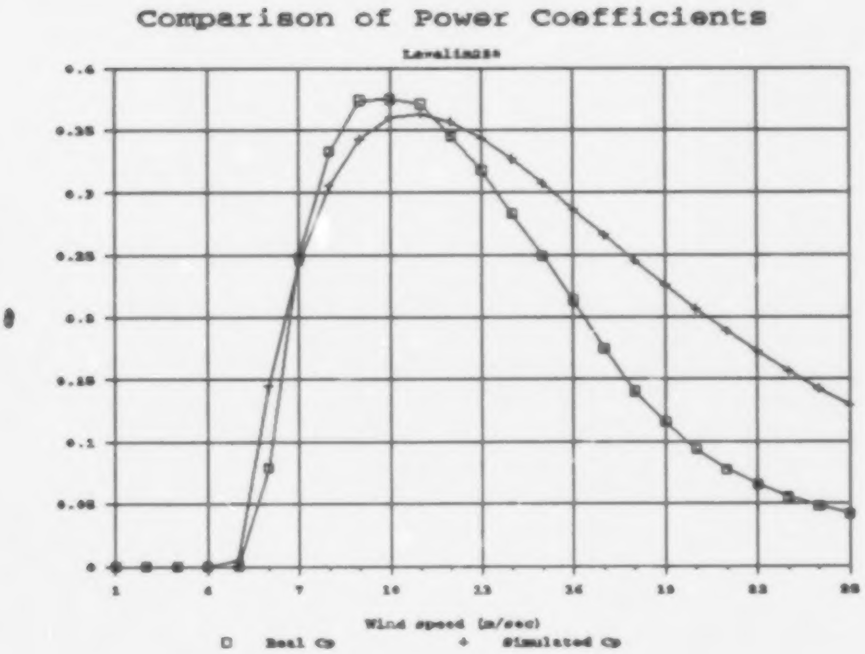

Figure 2

Wind Diesel Simulation - WNDDSL

WNDDSL is the main simulation program where wind/diesel system performance is evaluated over a 24 hour period. Using inputs from WNDSIM, WNDPWR, and LDSIM in conjunction with user supplied variables such as diesel size and number and diesel control parameters, WNDDSL computes, second by second, values of wind power as well as a system energy balance and energy flows to and from storage or a dump load and summarizes the hourly performance of the system with and without wind turbines.

Simulated wind power is calculated in a subroutine in the WNDDSL program using second by second wind data from WNDSIM and the wind turbine power curve from WNDPWR.FOR. Since the power output of the wind turbine has fewer fluctuations than the wind speed output of an anemometer, a transfer function is required to reflect the filtering effects of the wind turbine. The program uses a weighted sliding average filter to eliminate high frequency components.

To evaluate the accuracy of the subroutine, a program, PWRWND, was developed by J. Keller to monitor the function of wind power conversion in the WNDDSL program. PWRWND was evaluated by comparing the data of real power output from an Enertech E44-40 and a Carter 25 KW wind turbine with simulated power from the model based on identical wind input data. At lower power levels where the fluctuations in wind speed translated into variations in power output the correlation between actual and simulated power outputs were good. However problems were encountered at higher wind speeds. Results show a poor correlation between actual and simulated power levels in the high wind range where the power curves 'level off'. The binned data in figure 3 illustrates the real and uncorrected simulated results of power distribution for a one hour period near rated power for the Enertech. Figure 4 shows that the simulated output of the uncorrected model is unusually stable over the one hour period. Corrected power is shown inverted in these figures for clarity. Similar results were observed for the Carter wind turbine.

Since the results from wind-power simulation model do not reflect the actual power output in higher winds the program was modified to improve simulation results.

When hourly files of one hertz power output data from the Enertech at various wind speeds were analyzed, it was evident that power distributions within each small wind speed range were close to Gaussian distributions. Figure 5 shows the results of distributions of power output from Enertech wind turbine at wind speed of 8.5 m/sec. Similar results were evident in higher wind speed ranges as well. Modifications were made to the PWRWND model by introducing a 'power belt' at each wind speed that was normally distributed about the power curve into the program. Power output was simulated by superimposing random signals with a normal distribution on the average computed power value. The recalculated results showed much better correlation between the actual and simulated power outputs for both Enertech and Carter wind turbines. Figure 6 shows the corrected simulation results with real power data from the Enertech wind turbine. The corrected power dstribution curve in figure 3 shows the much better correlation between actual and corrected simulation results.

Ontario Hydro Model

The Ontario Hydro model has a number of desirable capabilities. Since it utilizes the commonly used Lotus format it is relatively simple to use and most people, with some practice time would be comfortable with it. It also performs the the required functions at a reasonable speed and is versatile enough to allow different power supply options to be added or deleted quickly. The presence of the quality graphics capabilities in the Lotus program is a very attractive option. The size of the spreadsheet does require an extended memory manager and since no computers at AWTS have this option, running the program often exceeded the memory requirements of the computer.

The model utilizes one week of real data as input to the simulation program. While this provides realistic variations in data, care must be taken to ensure the selected data is representative of the period chosen. It also requires that actual data be available before simulation begins.

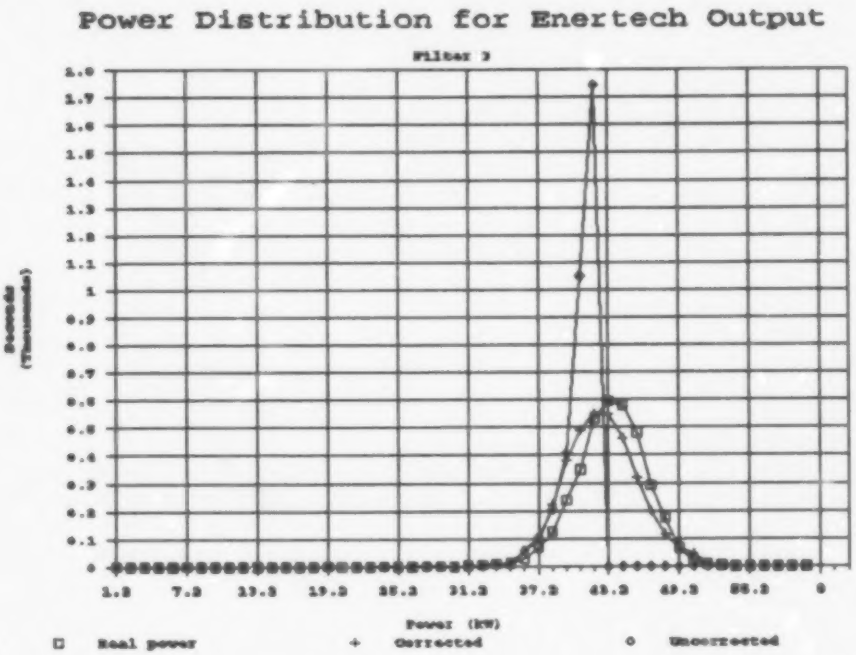

Figure 3 - Power distribution at actual averaged power of 43.3 Kw.

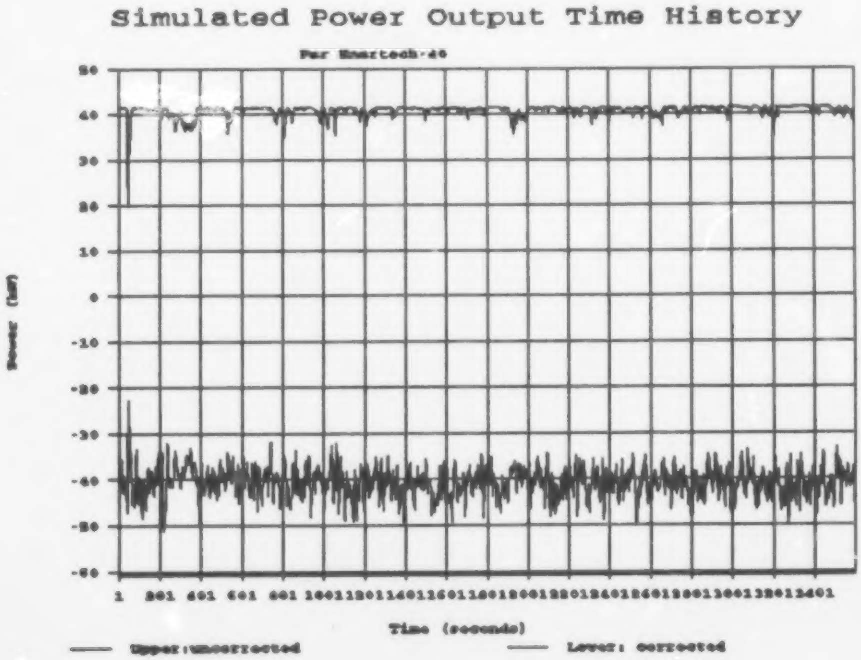

Figure 4 - Power time history at averaged power of 43.3 Kw.

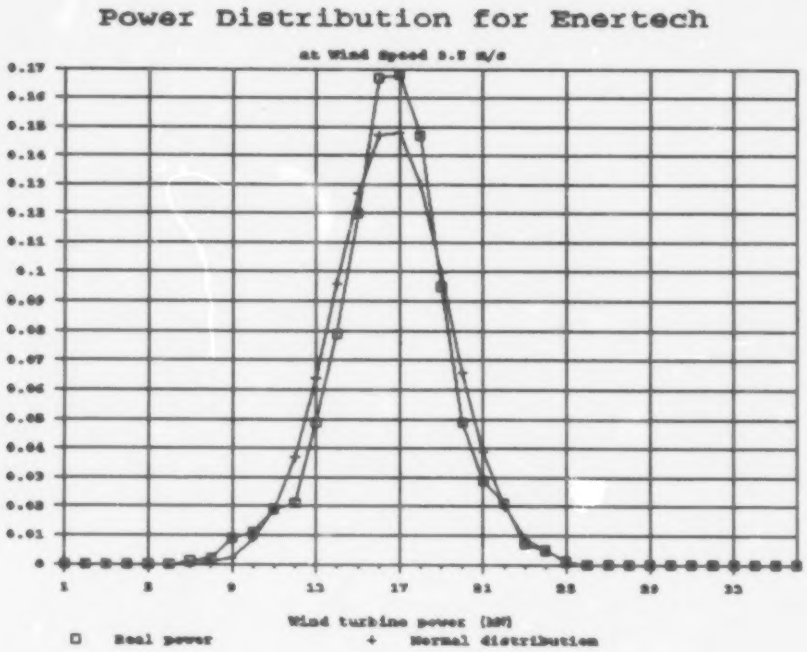

Figure 5

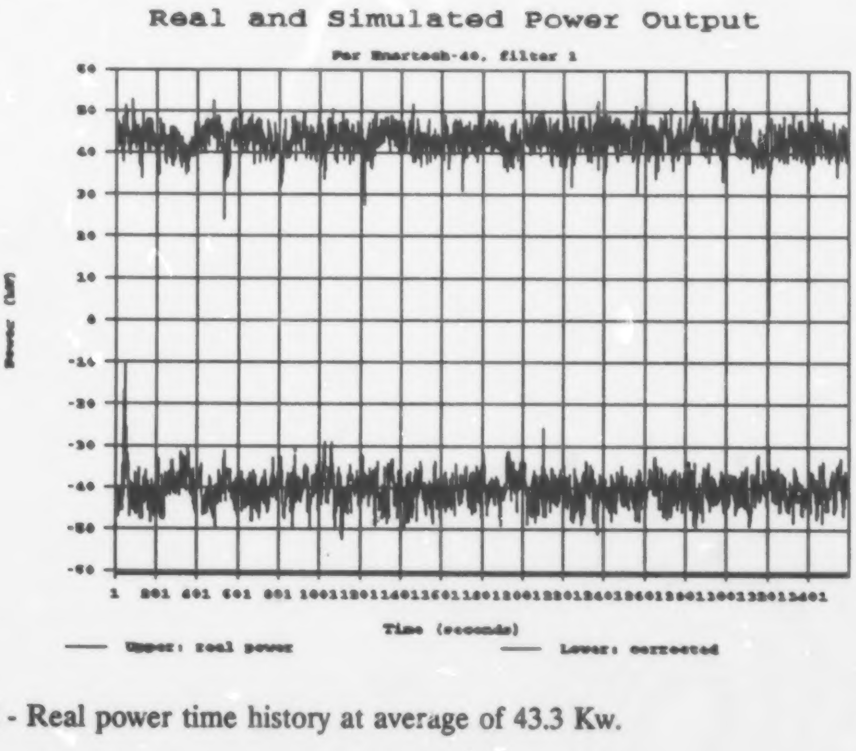

Figure 6 - Real power time history at average of 43.3 Kw.

The algorithms for calculating wind power and diesel fuel consumption are simple but they are relatively accurate. Table 1 shows relative accuracy of generic Cp curves on energy production. The selection of the wind turbine in the model is not directed towards any commercially available units. While having the option of changing the rotor speed and diameter is helpful in optimizing an installation, available power curves from commercial wind turbines would be helpful. The model limits simulation of up to two diesels only, adequate for most small communities but less than required for many larger installations.

The model performs a thorough economic analysis on renewable energy supply options that might be considered. Given that most emphasis in wind diesel modelling has concentrated on the technical aspects this is a very important consideration.

Table 1
Comparison of Actual Cp curves and Simulated Cp curves

	NDK150	VTA100	BON150	L250
EMR	10.7%	20.5%	- 24 %	8.9 %
Ont. Hydro	22 %	30 %	- 21 %	

IREQ Model

The IREQ model uses an interface worksheet, AUTO123.WK1, to link all the other worksheets. This makes the model easy to understand and use. Like other models it takes some time to become familaiar with this model.

A Rayleigh distribution is used to represent annual wind distributions, so the simulated wind regime can represent seasonal wind distribution fairly accurately with little input data requirements. The use of simulated wind data based on Rayleigh distribution limits the use of real data or extremes of data in the model. This makes little difference for average performance analysis but could be helpful for some analysis.

Power curves from seven commercial wind turbines are available in the program and additional power curve can be added if the existing curves don't match the wind turbine desired. The use of actual power curves, which can be combined as desired, provides an accurate and flexible representation of wind power available. Wind shear effects at site, can also be simulated to more closely simulate actual wind turbine output.

The consumer load is simulated by specifying peak load, capacity factor and maximum and minimum loads. These inputs are used, along with a second order Fourier function, to compute hourly load levels.

Diesel simulation permits the user to define diesel fuel consumption characteristics individually and to specify operating strategy. This makes the model capable of simulating most wind/diesel systems in a wide range of operating strategies.

The model does not perform economic analysis.

WDILOG

WDILOG-1, the version evaluated in this program is presently being upgraded to further refine some of the simulation functions in this model. Both versions of the model will use the Cypros/Sim program, that has powerful graphics functions. The model has a very impressive presentation of results.

Simulations can be carried out over a range of time periods. This makes the model capable of simulating short term system behaviour as well as performing longer term performance analysis.

Data for the model can be provided by actual wind and consumer load data or the data can be generated by providing average values to a simulation routine. Although this simulation permits evaluation over either long or short term, no frequency components are considered in the simulated functions. This may reduce system accuracy in simulations in short time increments.

Wind power can be computed by either using generic C_p curve within the model or selecting existing power curves for specific wind turbines. These two options permit a great deal of flexibility in evaluating different system configurations. Wind power output is computed directly from the power curve. This may also reduce the accuracy of system simulation in short time increments.

The minimum operating load of the diesel engines can be specified from typically accepted values of about 30%, down to -50% load. This enables analysis of the recently proposed strategy of negative diesel operation to be evaluated. Diesels are considered as a unit in this version of WDILOG and no optimization of diesel operating strategy is possible.

OPERATIONAL COMPARISON OF MODELS

Bench Tests

General comparisons for the four wind/diesel simulation models were made by using hour by hour real wind and community load data from Ford Severn for a one week run.

In the simulation, two diesels with rated power of 260 kW and one Enertech-40 wind turbine were selected. Assumptions were made of intermittent diesel operation with 20% minimum diesel rated power; second diesel being shut down at 20% of total rated power and being brought on line at 40% of the first diesel rated power. No storage system was used. Table 2 shows the simulation results.

Table 2
Bench Tests and Simulation Results

	Demand KWH	Diesel KWH	HAWT KWH	Dump KWH	Fuel Cons. (L)	Fuel % Saving
EMR	16987	16326	714	52.63	5447	3.6 %
EMR*	16987	16170	879	63.68	5401	4.3 %
Ontario Hydro	16936	16142	794	0	5532	3.0 %
WDILog	16964	16322	642	0	7614.7	2.1 %
IREQ	16479	13733	1845	82.4	4741	6.0 %

*EMR Modified

Field Tests

System Description

Performance validation for the four wind/diesel simulation models was carried out on the AWTS wind/diesel test bed. The test bed consists of two 50 KW Volvo diesel engines driving 50 kW, 1200 RPM KATO synchronous generators. An Indal 35 KW VAWT, an Enertech E44/40 KW HAWT, 77.5 kW demand load, 40 KW dump load, synchronizing switchgear, control devices and related instrumentation and a data acquisition system are all part of the system. Diesel on/off control strategy was applied in the field tests. Diesel One supplied prime power throughout the test while diesel Two was operated as required to meet the system demand.

System Control and Data Acquisition

The wind/diesel test bed currently uses two data acquisition systems. A Campbell Scientific CR21XL datalogger monitors all the inputs at a one hertz rate and provides 10 minute averages of all the values. This unit operates continuously and provides a permanent record of the system performance in the AWTS data system.

A Burr Brown PCI20000 instrumentation package installed in an IBM compatible PC-computer, provides data acquisition capabilities at higher speeds when necessary and also controls the wind/diesel system. A data acquisition mother board installed in an expansion slot in the computer has special function modules attached to provide the necessary acquisition functions. The system has 32 digital I/O, 16 analog inputs, 2 analog outputs and 4 counter/timer channels. A commercial software package, Labtech Notebook, integrates the functions of data acquisition, system control (with both open and closed loop control capabilities) and data analysis. Detailed system description and instrumentation is described in Wind-Diesel Activity [17].

Field Test Procedure

Field tests were carried out on the AWTS wind-diesel test bed over two 24 hour periods to evaluate the results of the simulation programs.

A 24 hourly community load data for weekday was created by using IREQ model with peak load of 70 kW and load factor of 0.6, and then EMR's LDSIM program for 24 hour second by second data with load turbulence of 10%. The 24 hour second by second decimal load data were converted into binary data by using a data conversion program and then fed into computer for diesel loading. In operation the control system provided second to second variations in load, representative of load variations in a typical remote community.

Throughout the period of the test, diesel#1 provided prime power and ran continuously. The closed-loop function of Labtech Noteboook allowed the second diesel to be controlled according to the diesel load control strategy. During the test, diesel#2 would be requested to stop at 20% total diesel rated power and to start at 80% of diesel#1 rated power.

For the first 24 hours, the diesels provided all power to the system with diesel#1 operating continuously and diesel#2 operating as required by the control strategy. For the second 24 hour period, the Enertech wind turbine operated in automatic mode displacing diesel fuel when it operated. Community load profiles for the two 24 hour periods were identical.

The dump load was energized to control the minimum power level on the diesel generators at 0 kW. This power level can be easily adjusted to permit any desired operating minimum, 0 kW was chosen to ensure significant levels of penetration were obtained in the short test period.

Although the wind/diesel validation test ran for only two 24 hour periods the data and results were pro-rated to provide a one week simulation run. Data used in the test run was used as input data for the model validation tests.

Data, acquired on six channels at a rate of one hertz, was stored in files of one hour time periods for later analysis. The six channels monitored included: system load, diesel power, wind turbine power, wind speed, diesel fuel flow rate and dump load. Comparison of results from field test and simulation models are listed in table 3.

The following assumptions were made in the setup of individual models to simulate the field tests:

- All models used identical hourly averaged wind data collected from the field tests, except for the IREQ model which used wind data averaged over the entire test. The specifications of input to the individual models for the simulation run are listed below.

- EMR/EMR modified: use of filter 3 and Enertech power curve as well as the same diesel control strategy as in the wind diesel field test. Diesel fuel consumption from generic 50KW diesel.

- Ontario Hydro: input initial wind turbine parameters such as rotor diameter and rotational speed of the Enertech turbine.

- WDILOG: input initial wind turbine parameters and one minute simulation time step.

- IREQ: use of the same diesel control strategy as in the field tests and the same diesel fuel consumption curve as in EMR model.

Table 3
Field Tests and Simulation Results

	Demand KWH	Diesel KWH	HAWT KWH	Dump KWH	Fuel Cons.	Fuel Savings
Field Test	7325	4178	3462	315	1672	30%
	6972	6978	0	0	2388	Ref.
EMR	7112	4011	3318	219	1554	38.5%
EMR*	7112	4207	3122	182	1624	35.7%
Ont Hyd	7056	2819	4874	637	848	54.1%
Wdilog	7060	4108	2952	0	1579	32.9%
IREQ	7056	4019	3405	370	1438	41.8%

DISCUSSION OF RESULTS

Bench tests on the conducted on the various models yielded similar results. Because the actual data was taken from a low wind speed site, Fort Severn, the fuel savings were small. IREQ's model preicted fuel savings considerably higher than the others because it assumes a Rayleigh distribution will occur over the time period of interest. Clearly the distribution over the period examined was not a Rayleigh distribution.

In the field tests summarized in table 3, actual test data resulted in a 30% fuel saving when wind was introduced to the system. Demand KWH variation was due to internal AWTS demand variation.

EMR model (unmodified) estimated a 38.5% saving while the modified version estimated a 35.7% saving. Estimated wind energy differs slightly because of the randomness of some variables. The modified version would have been more accurate if the turbine had been operating in the stall region of the power curve but in the tests conducted the power levels were generally low enough that both models were relatively accurate. Fuel consumption curves were taken from the generic curves within the model which vary slightly from AWTS diesel curves. This results in some additional inaccuracy in the predicted fuel consumption.

Ontario Hydro model overestimated fuel consumption considerably. This error was due in large part to the use of the generic power curve coupled with high average wind speeds for the test (9 M/Sec.). The generic curve overestimates power output at high windspeeds. Dump load is high as a result.

WDILOG underestimated wind energy output as a result of the simple generic Cp curve. The resulting diesel fuel consumption is high but the linear diesel fuel consumption curve compensates for this and estimates fuel savings quite close to actual. Dump load is zero as a result of the negative power option on the diesel engines.

IREQ's model used the actual power curve as an input and the resulting wind energy calculation was very close. The diesel energy estimate was very good but using a generic diesel fuel consumption curve total fuel consumption was slightly underestimated.

CONCLUSIONS AND RECOMMENDATIONS

All models exhibit similar characteristics in use. After some time for familiarization, all are easy to use. Also, all models have both strong and weak points, depending on the specific application for which the model was designed and what input data is used. Most of the weak points can be addressed by careful application of the existing models.

Several conclusions can be made based on the limited test data obtained;

- It must be recognized that the data base gathered in the field test is very small and this can distort results if care is not taken. Taking data from a 24 hour run and extrapolating it into one weeks data or projecting effects on a one years operation is risky.
- Nonetheless, some points were evident. Most models projected fuel savings with reasonable accuracy. Where accuracy was poor, reasonable cause could be found for the inaccuracy. Most of the inaccuracies were caused, either by the use of generic curves that were either too simplistic or did not represent actual equipment used, or by results distorted by the small data base used.

- It is clear that errors developed in models are cumulative. Any intermediate miscalculations in the model affects projected fuel savings. Accuracy throughout is necessary.

These models are all quite accurate at calculating fuel savings. Each represents the results of the developer's priorities. For the Ontario Hydro model , evaluation of various renewable energy options and consideration of economic implications were important. The EMR model emphasizes detailed energy flows over relatively short periods. The IREQ model permits easy entry and changing of input data while the WDILOG model emphasizes versatility in its capability to model both short term and long term applications.

Two recommendations are evident from this analysis:

- Additional detailed studies are required to properly document short term wind-diesel performance. Fluctuations in power levels and system stability are necessary to better understand the implications of wind-diesel operation and by understanding the short term variations better, the longer term models can be made more accurate.

- Discussions should be initiated to determine exactly what parameters are of importance in wind-diesel modelling. Little concensus appears on the use of such variables as actual data versus simulated data, model format, community load characteristics and other parameters

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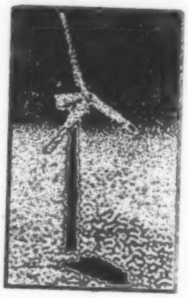

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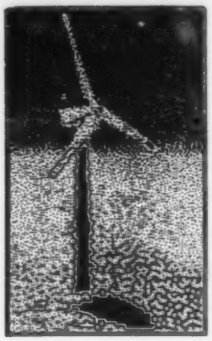

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